DESIGN AND IMPLEMENTATION OF A SIMULATION TOOL TO STUDY WAIT TIMES IN CATARACT SURGERY

by

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Abstract

Eye cataracts are a common problem for senior people. Long wait times for cataract surgery degrade the patients' quality of life. Reduction in long wait times in eye cataract surgery has got importance as one of the five major priority areas in the health care systems in Canada. The main contribution of this thesis is to design and develop a discrete event simulation tool in JAVA to study the wait times (wait time 1 and wait time 2) for patients in cataract surgical procedure. Two cataract surgical procedures are simulated in the simulation tool; Northern Health Cataract Surgical Model (NHCS Model) and Cataract Surgery Generic Model (CSG Model). Two alternative patient referral methods (refer patients to the surgeon with the least number of patients and uniform distribution of patients) are proposed and compared to the existing method to examine which method results in reduced wait times. The impacts of changing the resources (surgeon and OR) on wait times were analysed. The Manitoba Cataract Waiting List Program (MCWLP) priority system is simulated and compared to the existing FCFS policy to see whether the scheduling of patients for surgery based on priority improves wait times. Experimental results show that the two proposed methods significantly reduce wait times. It is found that Northern Health would meet the target wait time 2 (16 weeks) if one more OR (total of two ORs) is allocated for cataract surgery. The use of priority scheduling did not show any improvement in wait time 2. Increasing budget or number of resources is not always easy for any health care authority. This thesis suggests that, if Northern Health authority changes the existing patient referral method, it would definitely reduce wait times for patients.

Dedicated to my family

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Chapter 1

Introduction

Long wait times for patients in the health care system is a concerning issue in Canada and is drawing increased attention. The Canadian Institute for Health Information (CIHI) has found that Canadian patients face longer wait times for both specialist/surgeon appointments (wait time 1) and elective surgeries (wait time 2) [28]. This problem is concerning to the Canadian health care system as mentioned in the "a 10-year plan to strengthen health care" [12]. Hospital managements, doctors and researchers are trying to identify the causes of long wait times and possible solutions so that patients can receive treatment within an acceptable time period.

Some of the main reasons for long wait times identified in the relevant literature are:

- lack of physical resources (operating rooms (OR), post-operative beds, beds for inpatients, and the availability of ORs and beds)
- lack of human resources (doctors, anaesthesiologists, nurses and other staff)
- improper scheduling of patients waiting to meet a surgeon or have surgery
- inefficient use of current resources
- unavailability of patients for surgery (no shows).

The cancellation and rescheduling of surgery also increase wait times. Usually, a surgery gets cancelled for the following reasons: a preoperative evaluation before surgery, associated medical conditions, and patient's insurance problems (lack of coverage) [6, 34, 35, 47].

According to the World Health Organization (WHO), eye cataract is the main cause of 51% of the world's blindness [2]. Due to long wait times the patients suffer from different types of problems. Therefore, the reduction of wait times for cataract surgery has recently received higher level of importance.

The Wait Time Alliance (WTA)[1] has proposed wait time benchmarks for five priority procedure treatments including cataract surgery [3]. For cataract surgery, a patient should be operated within 16 weeks of a specialist making a decision that the patient requires cataract surgery (wait time 2). In most cases, health authorities face difficulties in meeting the standard wait times.

This thesis presents a computer simulation tool that can be used to study wait times of cataract surgical procedure. A simulation study of long wait times of Northern Health (NH), the local heath care system, has been done as a case study.

Next the motivation, contributions, and the organization of this thesis are presented.

1.1 Motivation

Long wait times for cataract surgery degrade the patients' quality of life by causing several problems [9, 18, 23, 45]. Long wait times usually increase different types of injuries or falls when they go for shopping, walk on uneven ground, climb up and down stairs, and travel. Their daily life activities such as eating, bathing, dressing, grooming, and home making are also affected [25]. They also face problems in taking care of dependants, reading books and newspapers, watching TV, making phone calls,

[1] WTA consists of several medical speciality associations in Canada that works on how to get timely, appropriate, and equitable access to the health care.

cleaning, and washing. The loss of driver's licence and difficulties at work place are another two important impacts on quality of life. As a result of these problems, patients lose their independent life style and often have to depend on others for the above mentioned activities. This motivates us to find ways to reduce the wait times for cataract surgery.

Cataract surgery is mostly an outpatient surgery. For outpatient surgery, the patient does not need to stay in the hospital after surgery. Outpatient surgical procedures are becoming an important part of the health care system because of its effectiveness [15]. After reviewing the available literature, the following issues about eye cataract surgery are found:

- Several research studies have been done on eye cataract surgery; the main objectives of these research studies were to reduce patient wait times and promote effective resource utilization.

- Discrete event simulation method has been used frequently in this area. One important benefit of this approach over others is that it allows researchers to represent complex scenarios of the system, and variability with different variables [15, 56]. Discrete event simulation method is appropriate for feasibility study of a system, modeling complex systems such as the health care system for its flexibility and cost effectiveness [59]. Most of the research papers, so far, have adapted different simulation tools for analysing this issue rather than developing a custom tool well-suited to the research problem.

- The widely used First Come First Serve (FCFS) policy to schedule patients for surgery is not always useful and effective [10, 55]. In FCFS policy a patient with a major problem waits almost the same amount of time as a patient with minor problem because he/she[2] enters the surgical system later.

- Most of the times, it has been seen that, a patient prefers to go to a surgeon who is popular, or a GP/family doctor refers a patient to a specialist/surgeon

[2]she refers to he/she in the rest of the thesis.

whom she knows. Therefore, some surgeons receive comparatively more referred patients. As a result, some of the surgeons' wait lists are longer than others and their patients have longer wait times. No suitable patient referral methods from GPs to surgeons are discussed in the relevant literature.

- We did not find any research work that considered both wait time 1 and wait time 2 of cataract surgical procedure.

- We did not find any research work that focused on the development of a comprehensive simulation tool that offers both scheduling of the patient wait list and managing the resources (surgeon and OR) together for cataract surgery.

Another source of motivation for this thesis work was the current situation of Northern Health (NH)[3]. Northern Health fails to meet the WTA target wait time 2 of 16 weeks for cataract surgery [28]. Also, the patients have to wait longer to have an appointment with a specialist/surgeon (wait time 1). Although the province of British Columbia has improved in the total number of cataract surgeries performed per year from 31,215 to 47,659 since 2001 [19], NH is still missing the target set by the BC Ministry of Health. NH was only able to perform 53% of surgeries within 16 weeks for the fiscal year 2010-2011 [19]. Consequently, NH looks forward to performing more surgeries in coming years so that patients get operated in an acceptable amount of time.

Another issue for NH is the expected number of incoming cataract patients for the coming years. According to the Statistics Canada, the population of Canada is growing every year (31.02 million in 2001 to 34.88 million in 2012) [1]. Although the population of Northern BC is expected to increase by just 7.5% from year 2011 to 2025 with an average of 0.5% every year, NH is going to have their senior population nearly double from 2011 to 2025. The chart in fig. 1.1 shows that in 2025, the 65 plus population will be double that of 2011. The expected increase of 65 plus and 75 plus

[3]NH is the health care authority of British Columbia that provides health care facilities to ensure quality care for more than 300,000 people in the northern part of British Columbia.

population will be 85% and 88% respectively during this time period. As a result, the number of cataract surgeries is expected to increase as well, since generally older peoples are more susceptible to eye cataracts [39].

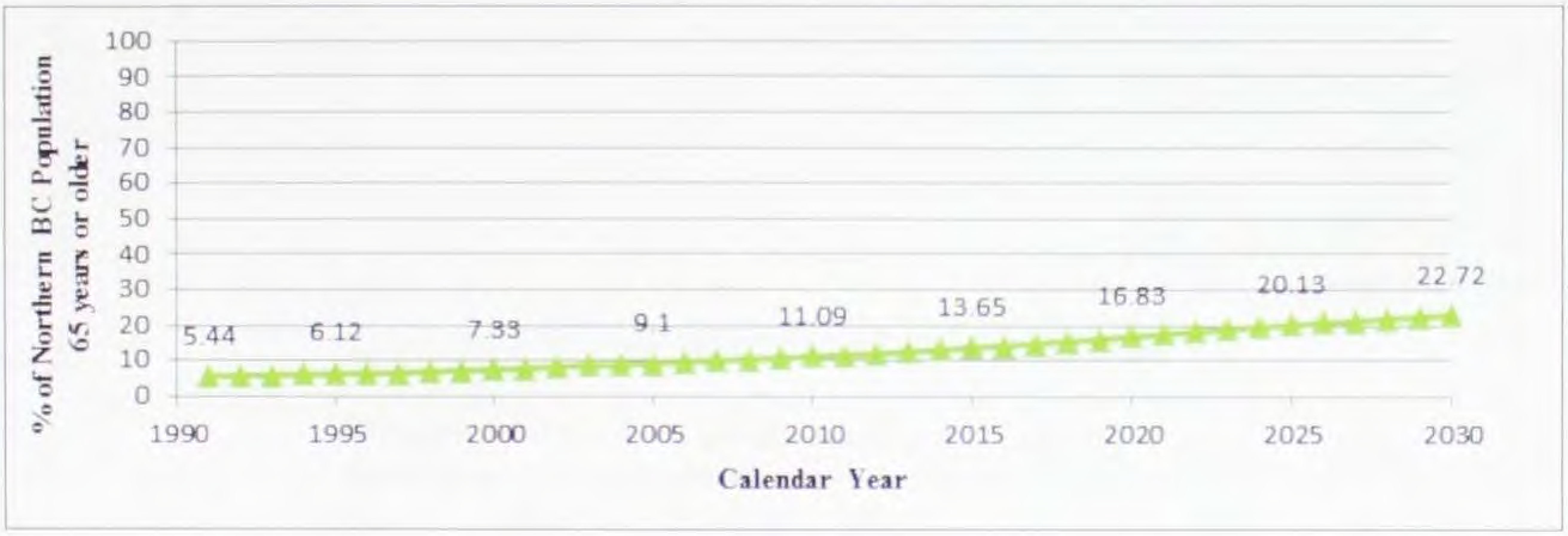

Figure 1.1: Percentage of 65 Years or Older Population in Northern British Columbia

The historical data of NH supports that eye cataract surgeries are more prevalent for seniors. Since 2008, More than 70% of the patients were 65 or older among the total number of cataract surgeries performed yearly by NH. Fig. 1.2 is the graphical presentation of this statistics.

Figure 1.2: Patient Trends for the Cataract Surgery in Northern Health (2008-2012 July)

Because of the above mentioned reasons, NH is interested in knowing the possible reasons of both types of long wait times in order to make best use of their resources to gain optimal outcomes. No research on cataract surgery, to the best of our knowledge, has been done for the Northern British Columbia.

All these issues and limitations related to cataract surgery motivated us to conduct a research on the cataract surgical procedure, by simulating different scenarios, to find out the possible causes of long wait times, and to propose improvements that could reduce wait times. The existing simulation studies used generic simulation packages such as Flexsim, Simul8, Arena, Extend, and SLX. [10, 32, 58, 63], there is no stand-alone simulation tool specifically developed for cataract surgery. Therefore, we decided to develop a simulation tool from scratch.

1.2 Contributions

The objective of this thesis is to develop a comprehensive discrete event simulation tool for the cataract surgical procedure in JAVA. The simulator could be used to create and analyse various scenarios that helps in finding the possible factors that cause the long wait times for patients for wait time 1 and wait time 2. It also can be used to show the possible impacts if the key resources (surgeon and Operative Room (OR)) are changed. This could help a health authority, such as NH and other decision makers, to identify where they can best invest their resources for cataract surgery in order to achieve the best outcome for the patients. This thesis has the following contributions.

1. A simulation tool specially designed for cataract surgical procedure. The tool is used to simulate two surgical procedural models: the Northern Health cataract surgical procedure model, and a generic model that could be followed by any health authority. It could be used to show alternative scenarios that affect the wait times such as changing (increase or decrease) the amount of resources (surgeons and Operative Rooms), and scheduling of patients and ORs. The tool has the ability to forecast the possible number of incoming patients for future years based on the patient arrival rates.

2. Three patient referral methods, from family doctors/General Practitioners to surgeons (to get first appointment), are simulated in the simulation tool in order to show which method results in reduced wait time 1 and wait time 2.

3. A priority scheduler (MCWLP) is simulated in the simulation tool to schedule patients for surgery based on urgency. The aim is to schedule the patient wait list effectively in order to reduce wait time 2.

The simulation tool is simple and easy to use by the end user, therefore, the decision makers can use it to understand various scenarios and make informed decisions.

We are interested in exploring a number of research questions, related to cataract surgery wait times:

1. How to reduce wait times of patients?
2. What is the impact of the patient list size (both current and backlog patients) on wait times and total surgery done?
3. If NH does not increase resource or change scheduling, what will be the performance of the surgical procedure in the future?
4. How accurate is the simulator to produce historical outcomes?
5. What are the main factors that cause long wait times?
6. How much more resources does the NH need to meet the target wait time?

1.3 Thesis Organization

This thesis is organized as follows. Chapter 2 introduces the cataract surgical procedure, the scheduling of the patient, and the scheduling of the OR. A review of related research is presented in Chapter 3. The structure and implementation of the proposed simulator is illustrated in Chapter 4. Chapter 5 presents the simulation experiments and observations. Chapter 6 concludes this thesis and includes future research directions.

Chapter 2

Cataract Surgery and Scheduling

A cataract is the clouding of the lens of the eye that prevents clear vision. This cloudiness can cause a decrease in vision and may eventually lead to blindness [2,38]. It is a common problem in older people. Cataract surgery replaces the lens of the eye with a plastic lens to improve the eye sight. It can be done within 20 to 25 minutes for most patients [61]. As most of the cataract surgeries need local anaesthesia, no anaesthetist is required. A surgeon and two nurses are enough for this surgical procedure. It is mostly an outpatient surgery, therefore, the patient does not need to stay in the hospital before and/or after the surgery. Cataract surgery has a high level of success (success rate is approximately 98% with minimal complications) [11,40,51]. Some common complications of this type of surgery include posterior capsule opacity, YAG laser capsulotomy risks, and dislocated intraocular lenses [64].

In this chapter, the cataract surgical procedure of Northern Health, Prince George is discussed. We begin with the health care terminologies used throughout this thesis.

2.1 Terminology

- **Patient:** A person who is enrolled to get medical treatment [26].

- **Elective and non-elective patient:** Based on the urgency, patients are divided into elective and non-elective patients. A patient who is admitted in the hospital and receives surgery on a pre-scheduled date is called an elective patient. A patient who needs immediate care and does not have an appointment is considered a non-elective patient. Non-elective patients are further subdivided into urgent and emergent patients. An urgent patient may wait for a short period of time to receive treatment whereas an emergent patient should undergo surgery as soon as possible [14].

- **Inpatient and outpatient:** A patient admitted to a hospital before an operation and stays in the hospital bed afterwards is called an inpatient. An outpatient does not need to stay in the hospital: she comes to the hospital, undergoes surgery, and gets discharged, all in the same day.

- **Wait list:** The wait list is a list of referred patients who are waiting either for the first visit with surgeon or surgery.

- **Backlog patients:** Referred Patients who are waiting either for the first meeting with surgeon (Backlog 1) or surgery (backlog 2) from the previous year.

- **Family doctor or General Practitioner (GP):** A family doctor or GP[1] analyses and treats sicknesses, physical disorders, and minor patient wounds. She is the primary contact point to a patient's health management, and provides health care to the patient [13].

- **Wait time 1:** The wait time of a patient between the day she is referred by the GP to the day she has an appointment with the specialist.

- **Wait time 2:** The wait time of a patient between the day of a surgery booking to the day the surgery is performed.

- **Benchmark time:** Medically expected maximum wait time for a patient receiving a surgery (in five priority areas: cardiac surgery, vision restoration, orthopaedics, diagnostics, and cancer treatment) as set by the province of British

[1]GP refers to GP/family doctor in the rest of the thesis.

Columbia, Canada [50]. The wait time 2 benchmark for cataract surgery is 16 weeks.

- **Operation slate:** The fixed time period allocated to a surgeon to utilize the available OR on a scheduled day, where the surgeon performs a list of scheduled surgeries.

2.2 Cataract Surgical Procedure in Northern Health

The surgical procedure for cataract surgery followed in Northern Health is illustrated in fig. 2.1. The durations of wait time 1 and wait time 2 are shown in round dotted and dashed arrows respectively.

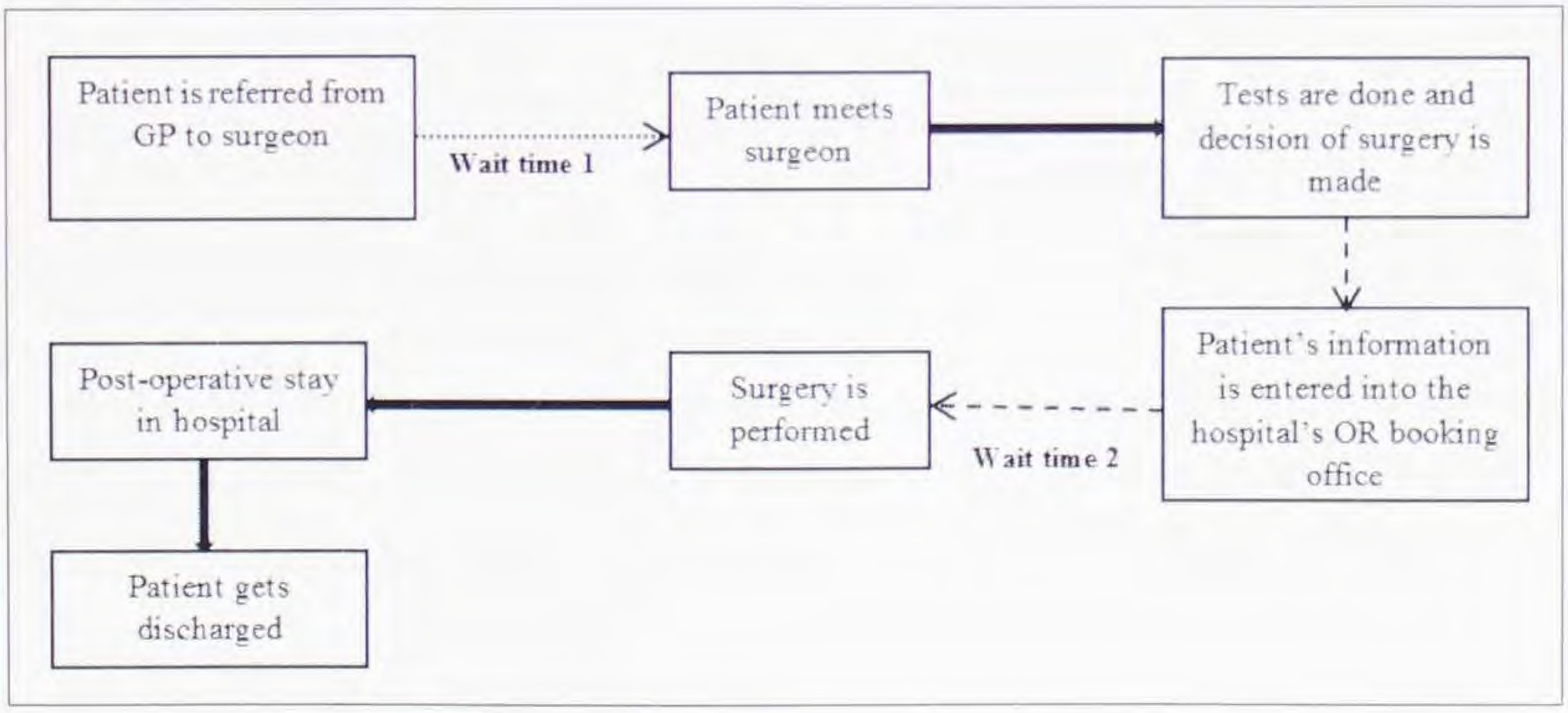

Figure 2.1: Surgical Procedure for Cataract Surgery in Northern Health

In this surgical procedure, when a GP finds that a patient has an eye cataract problem, she refers the patient to a specialist/surgeon[2]. The referred patient then waits to get the first appointment with the surgeon (wait time 1). When the surgeon checks the eye of the patient and decision to undergo surgery is made, the patient's information is entered into the hospital's OR booking office, and the patient waits to

[2]Surgeon refers to surgeon/specialist for the rest of this thesis.

get the surgery (wait time 2). The surgical procedure is completed when the patient gets discharged from the hospital after the operation on the day of surgery. All health authorities in Canada follow the very similar procedure for eye cataract surgery with some exceptions that might depend on the environment, budget, and resources of a hospital.

The following three key components of this cataract surgical procedure need further explanation:

- **Patient referral method**: How do GPs choose surgeons to refer patients?
- **Patient scheduling**: How are the patients scheduled on wait list?
- **OR scheduling**: How are the ORs scheduled for surgeries amongst surgeons?

Each of these components are explained in the following sections.

2.3 Patient Referral Methods

The way GPs refer patients to surgeons is a very important part in the surgical procedure. So far, there is no formal criteria used in NH to refer patients. Usually one of the following three ways of selecting a surgeon to refer a patient is followed:

- A surgeon who is popular in that field
- A surgeon who is familiar to the GP
- A surgeon who is familiar to the patient

Through these methods, some surgeons receive more patients, their wait lists are longer, and they perform less number of surgeries in comparison to the total number of patients they receive. As a result, the wait times can be longer. These long wait times increase patients' dissatisfaction as they start facing problems to perform activities of daily life.

To mitigate the issues stated above, two alternative patient referral methods that could improve the present situation and make optimum use of the existing resources are considered:

- Uniform distribution of patients among surgeons
- Refer patients to the surgeon with the least number of patients

Uniform distribution of patients among surgeons: In this method, a GP will refer patients uniformly to all surgeons. The GP will send patients to each surgeon one after another. This will avoid possibility of some surgeons being overloaded by patients. All surgeons will have almost equal number of patients; thus, it will ensure optimum use of the ORs also that follow blocked scheduling policy.

Refer patients to the surgeon with the least number of patients: To follow this method, the GPs need to have information about the total number of patients of all surgeons. Before referring a patient to a surgeon, a GP will check which surgeon has the least number of patients and send the patient to that surgeon. This referring method will create equal balance of patients among all surgeons. No surgeons will be overloaded and wait time will be comparatively less than the other referral methods.

2.4 Patient Scheduling

Patient scheduling is also referred to as wait list scheduling. Patient scheduling occurs at two different places in the surgical procedure: when the referred patients wait to meet a surgeon (wait time 1); and when the patients wait for surgery after making decision of surgery (wait time 2). The main purpose of this scheduling process is to select which patient to undergo the service next.

First Come First Serve (FCFS) is the most widely used scheduling policy in both cases. FCFS is very simple process, each patient is treated equally based on who arrives first; additionally, it does not consider the patient's health condition and urgency.

Some health care authorities in Canada and European countries have started using a priority scoring system to select the next patient from the patient list waiting for surgery. Different types of medical and social criteria are used to calculate the priority of each patient. The patient wait list is updated according to the priority of each patient at regular interval, and the patient with the highest priority gets treatment next. This is a flexible scheduling policy.

FCFS policy is used in Northern Health for both cases. So far, no priority system has been implemented.

2.5 OR Scheduling

OR scheduling is one of the most important of resource scheduling. This is also known as surgical scheduling. OR scheduling is the allocation of OR(s) among surgeons for surgery based on some criteria. One or more ORs are assigned for a specific surgery for a certain period of time to a surgeon or more for one day, two days, or every week day of a week.

Different types of allocation policies are used to assign the ORs among surgeons [31, 33, 42]:

- **Blocked scheduling:** In this scheduling policy, the ORs are assigned to a surgeon in a weekly or monthly periodic way. In this case, the OR is blocked for a specific surgeon, and it is a static process. Generally a block (a set of time blocks) includes more than one same type of surgery, atleast two or three surgeries, and equal durations for each surgery.
- **Non-blocked scheduling:** In non-blocked or open scheduling, the hospital authority does not hold or block the ORs for a specific surgeon; the surgeons instead send request for the ORs based on their number of required surgery

cases, and the ORs are scheduled dynamically according to their demand based on FCFS strategy.

- **Modified scheduling:** The modified scheduling is a combination of the first two scheduling policies. It follows the blocked scheduling policy with some operation slots left open (non-blocked scheduling) to keep the scheduling option flexible.

Most of the health care authorities follow the blocked scheduling policy to assign ORs due to its simplicity and efficiency [44]. The blocked scheduling policy reduces the setup time for surgery; once the OR is ready, the surgeon can perform a series of operations. Additionally, this policy maximizes the OR utilization because of its less OR idle time.

The way the blocked scheduling follows to assign the ORs amongst surgeons is known as round robin (RR) policy. The term 'round robin' is basically used in Computer Science for process scheduling. In this scheduling, the CPU is assigned to each process for a fixed time slice (also called time quanta) uniformly without any priority in a circular way [48]. Here, we mean that a resource (the OR) is assigned to one or more persons (surgeon(s)) in a circular way equally without any priority on each week day for a certain amount of time. So, every surgeon gets equal share of the OR in turn since this approach does not consider any priority. This is a simple and fair allocation process. In general, the number of surgeons who will perform surgery each day depends on the number of the allocated ORs for the surgery. Surgeons do not have any preferences to choose a specific OR amongst the allocated ORs. Each surgeon gets an OR randomly. A surgeon generally performs surgeries more than one week day in each week. However, it is seen that surgeons perform surgeries on fewer days than they spend visiting patients, each week. On a scheduled day, if a surgeon does not have any patient to perform surgery or the surgeon goes on vacation or to a conference, the assigned ORs remain unused most of the time.

Northern Health follows the blocked scheduling policy with some constraints. The constraints of this scheduling policy are:

- Each day only one OR is available for cataract surgery.
- The OR is available to one surgeon only.
- A surgeon performs surgery one day a week only.

In this thesis, we remove the resource constraints imposed by NH on the blocked scheduling and refer to it as generic blocked scheduling (GBS). More precisely, in GBS, more than one surgeon can perform surgery on the same day based on the number of allocated ORs. Surgeons might also perform surgery more than one day a week.

2.6 Summary

In this chapter, we have discussed the cataract surgical procedure of NH, different patient referral methods, and the scheduling of patients and ORs. We have mentioned the constraints of the NH surgical procedure and included some alternative and more generalized ways.

Chapter 3

Literature Review

The work presented in this thesis is related to the study of cataract surgical procedure, outpatient surgical procedure, patient wait times in the health care system, patient/wait list scheduling, resource management, performance metrics, and the simulators developed in this research area.

The available research works, on cataract surgical procedure, focused on the wait time 2 only. These works on wait time 2 showed how to improve wait time 2 through proper scheduling of resources and patients. We did not find any papers that directly talk about wait time 1 or how to reduce long wait times of patients between the GP referral and first visit with the surgeon. Some studies focused on the reduction of the wait time, on the same day, for outpatient appointments in order to control the patients' wait times for an office session. For example, the paper in [57] discussed different ways of booking outpatient appointment for each day, such as, pure overtime (keeps extra six slots or one hour everyday), double booking (two patients will be booked on each slot), and combined double booking and overtime. Most of the papers that talked about wait times focused on wait time 2. Wait time 1 got minimal attention by the provincial governments of Canada in the past [8]. However, the publishing of information about wait time 1 in the website has become mandatory in BC from April 1, 2014.

We have mainly categorized the available research into four major groups based on our observations: (i) Section 3.1: the effects of long wait times and patient dissatisfaction; (ii) Section 3.2: scheduling of patients/wait list scheduling; (iii) Section 3.3: scheduling/capacity planning; and (iv) Section 3.4: performance metrics used in this area.

3.1 The Effects of Long Wait Times and Patient Dissatisfaction

We know that older peoples are more susceptible to eye cataracts and most of the patients are 65 or older [22, 39]. Several surveys showed that long wait times for cataract surgery degrade patients' quality of life by causing several problems. Patients' dissatisfaction increase as the length of their wait times increase, the value of patient satisfaction has recently received a large amount of attention [53]. A report analysed the economic cost of the excessive wait times of Canadian patients and found that the costs per patient with excessive wait times for cataract surgery in British Columbia is 1,017 dollars per patient; the costs include patient costs, caregiver costs, and health care system costs [29].

Lundstrom et al. did a survey on 150 cataract patients in Sweden to show how their activities of daily life were affected by visual disabilities before their surgery [45]. Patients answered a questionnaire of six questions about their activities before and after the surgery, such as, mobility, household work, reading, watching TV, social life, hobbies and spare time activities, holiday and travelling, and ability to enjoy beautiful things. The result showed that 79.1% of the patients agreed that their quality of life improved after the operation.

Another survey based on patient interviews was done in England to find the factors that got the highest importance by surgeons that patients suffered most when they had long wait times for cataract surgery [18]. Those factors were reading, writing, recognizing faces, cooking, watching TV, driving, and care giving.

A research studied the literature about the outcomes of long wait times for cataract surgery [40]. This study evidenced that patients who waited for more than six months for surgery had reduced vision, a degraded quality of life, and their rate of falls was higher. It also mentioned that patients with three months or less wait times were satisfied. Dissatisfaction grows with longer wait times.

Expedited cataract surgery resulted in seven times improvement in the vision of patients compared to scheduled surgery [23]. This meta-analysis found that different types of injuries happen due to fall, when poor vision is a potential risk to fall. This research was done in the United Kingdom.

Conner-Spady et al. did a survey on the relationship between wait times and patient characteristics. The key findings of the survey was that due to long wait times cataract patients face more danger of falls, hip fractures due to falls, and motor vehicle crash [21].

A questionnaire based telephone interview was conducted in Hong Kong to know the reasons if cataract patients prefer to go to public or private sector for surgery and acceptable wait times for patients [16]. The Result showed that 90.7% respondents don't want to go to the private sector even after having long wait times due to unaffordable private fees. Acceptable maximum wait time by half of the respondents was 12 months or less. This study also mentioned that the wait times for surgery more than six months have several negative outcomes such as increased risk to fall and motor vehicle accidents.

A survey done on public and private patients of cataract surgery in Sydney, Australia, showed that public patients had to wait (38 weeks) nine times more than private patients (four weeks) for surgery, and the public patients did not get sufficient information about surgery compared to the private patients [53]. On an average, private patients were more satisfied than public patients overall, whereas public patients showed more satisfaction than private patients with respect to cost of surgery.

The above discussions explain that due to long wait times the patients falling rate is high, as a result, other accidents might happen such as hip and knee fractures. Patients lose their independent life style and depend on others more or less for the activities of daily life and others which cause patient dissatisfaction. Thus, study on long wait times for patients of cataract surgery has become a worldwide health care issue.

3.2 Patient Scheduling/Wait List Scheduling

In this section we discuss the scheduling of patients who wait for surgery. The patients wait for surgery in the wait list need to be scheduled in a proper way. Canadian residents believe that access to necessary health care services should be unbiased, and based on need and urgency [12]. This scheduling is an ongoing debate in the health care system in Canada. It is one of the most important factors in reducing the wait times for patients and increasing patients' satisfaction.

It has been seen that the First Come First Serve (FCFS) policy is not always useful in real life [10,55]. A patient whose status is urgent should get surgery before a routine patient, but in FCFS method, a patient who has severe eye cataract problems, has to wait almost the same amount of time for surgery as a patient who has minor problem(s). It is very important to decide on how to select the right person from the patient wait list for cataract surgery. We observed that mainly two types of criteria are used in priority calculation: social and clinical. The inclusion of social factors in priority calculation in cataract surgery was initiated in New Zealand. The decision was made after a public hearing about whether a patient's medical condition affects her ability to work, care for dependants, and independent life style [9]. It is very important to include the time that the patient has already spent in waiting into the calculation of priority; otherwise patients with low urgency status will never be able to take place on the top of the waiting list for surgery [49]. Several papers talked about this issue and developed prioritization systems to prioritize patients on the wait list for different surgical procedure such as general surgery, hip and knee replacement, and cataract surgery.

Mullen, in his study [49], covered prioritization formulas from early days to more recent ones. Early priority formulas were developed between 1960 and 1970. He mentioned that the first formula was developed by Luckman et al. (1969):

$$P = S^a D T^{w^b} \tag{3.1}$$

where P = priority score; S = social factor; D = disability factor; w = deterioration factor; T = time on waiting list (weeks); a and b are constants.

Some other priority systems are described below.

The prioritization system IRYSS-Cataract Priority Score (ICPS) considers eight criteria, that were chosen by a panel of nine ophthalmologists from 310 different scenarios [54]. They are:

- presence of ocular comorbidities
- visual acuity in cataractous eye
- expected visual acuity after the intervention
- visual function
- level of impairment of daily activities due to visual function
- visual acuity in the contralateral eye,
- type of cataract
- social dependence and the appropriateness of the intervention.

The Catalan Agency for Health Technology Assessment and Research Cataract Priority System (CCPS) includes six criteria used to calculate priority for cataract surgery [4]. They are:

- severity of disease
- probability of recovery
- difficulty in doing activities in daily life
- limitation on ability to work
- need help of caregiver
- difficulty in being a caregiver

The Manitoba Cataract Waiting List Program (MCWLP) is the first cataract patient wait list prioritizing provincial program in Canada [9]. This program has a central database that keeps track of all patients waiting for cataract surgery and sets priority for them. This program uses a questionnaire called the Visual Functioning index (VF-14) that includes questions to measure severity of functional dysfunction. Two social factors are included in the system: challenges at work because of visual deterioration and potential loss of driver's licence. Each ophthalmologist receives a list of his patients based on the monthly order of priority. This program shows a great level of equality because all patients are prioritized by the same criteria. However, this priority scoring system is criticised for some reasons: for over highlighting driving, for not giving importance to those patients who are the only caregiver to their dependants, and not enough points given for time spent waiting. Higher priority indicates higher impairment. The priority score is calculated as the sum of the following five factors:

- Functional impairment (100 – VF-14 score)
- Length of wait (no. of month waiting for surgery * 5)
- Work impairment (none = 0, mild = 10, severe = 25)
- Work driving impairment (no = 0, yes = 20)

- Potential loss of driver's licence (no = 0, yes = 15)

So the priority equation for each patient is

$$\begin{aligned} \text{Priority} = {} & \text{Functional impairment} + \text{Length of wait} + \text{Work impairment} \\ & + \text{Work driving impairment} + \text{Potential loss of driver's licence} \end{aligned} \tag{3.2}$$

The Western Canada Waiting List Project (WCWL) developed the cataract surgery priority criteria tool that computes the sum of seven weighted criteria [40]. They are:

- best-corrected visual acuity in the non-surgical eye
- best corrected visual acuity in surgical eye
- glare
- ocular comorbidity
- visual impairment
- other disabilities
- the ability to work, live independently and care for dependants

A study compared the three cataract prioritization systems: the IRYSS-Cataract Priority Score (ICPS), the Catalan Agency for Health Technology Assessment and Research Cataract Priority System (CCPS), and the Western Canada Waiting List project (WCWL) for cataract surgery. The comparison was done through coefficient methods, 95% limits of agreement and, kappa coefficient. It was found that these three systems have acceptable correlations, but they give higher importance to different criteria. ICPS gives more importance to clinical characteristics. The CCPS gives importance to patients who have severe visual impairment, who are helpless and can not take care of themselves, and who have dependants. The WCWL put more importance to visual acuity and function, and social condition of the patients. WCWL was found to be very significant in improving visual function and visual acuity [55].

A research on a Spanish health care system developed a discrete event simulation model in SIMUL8 that compares the prioritization system of cataract wait list to their current waiting list management system, First In First Out (FIFO) [20]. Priority calculation included the following criteria: clinical (visual impairment and recovery probability), functional (difficulty in daily life activities and ability to work) and social (someone need to look after the patient and be a care giver). This model measured the wait times of patients considering various factors (wait time of patients who were operated, patients who moved to the private sector, patients still waiting, and patients who died while waiting). The surgeon sets a priority score for each patient when added to the waiting list, and then the list is updated each time a new patient is entered into the list. The Outcomes of the different scenarios showed that the prioritization system reduced mean wait times by 1.55 months compared to FIFO, but patients with lower priority had excessive wait times.

Some non-clinical factors (social factors) were found to be significant in Manitoba that could vary the wait times of patients waiting for cataract surgery. For example, some factors are sex, age, socioconomic status, undergoing hospitalization while waiting, and region of residence are some of them [22].

An analysis was performed to know the preferences for criteria to prioritize cataract patients waiting for surgery among four groups of people (public, patients/relatives, health professionals, and specialists). The result showed that visual impairment got the highest importance in all groups, followed by difficulties in performing activities of daily life, problems for working people, being looked after by someone, and recovery probability [60].

The paper in [27] calculated a priority schedule of elective patients waiting for surgery for the West Australia Health Authority by using a simulation model built in Extend[1]. This paper showed how to schedule elective patients based on urgency. The simulator includes the whole surgical procedure that starts from a wait list of

[1]Extend is a message based simulation engine that has fast and flexible model building and execution facility [43].

patients, then admission of a patient in the hospital, followed by surgery performed in the operation theatre, and the postoperative stay in the hospital. The priority of each patient was based on urgency (urgent, semi-urgent, and routine), wait dates, and expected hours to conduct the operation:

$$\text{priority} = \text{urgency} + \text{wait date} + \text{expected hours} \tag{3.3}$$

The hospital authority receives the sorted (ascending order according to priority) wait list at the beginning of each week and selects the next patients for surgery with highest priorities.

Another prioritization system in Italy use the following equation to calculate priority of each cataract patient:

$$p = c * t \tag{3.4}$$

where, p = priority, c = clinical urgency status (progress of disease, pain or dysfunction, and disability), and t = wait times already spent [59].

The recent simulation model, in [10], provides the following priority calculation:

$$p = a(w/t) + (1 - a)r \tag{3.5}$$

where, p = individual patient priority, a = relative priority of patient (urgent or routine), w = current wait time = current simulation time-time of referral of patient, t = the specified target wait, and r = a random variable that is resampled for each patient when the waiting list is updated.

This model gets the waiting list, calculates the priority of each patient, and updates the wait list weekly. The key element that differentiates this model from others is that it computes priority to a specified target time. This model forecasts future wait list also. This priority system was applied to general surgery, orthopaedics, and ENT (Ears, Nose, and Throat).

Another simulation model PASTA (Priority Admission Strategy Analysis) was used in England to compare three different cataract admission systems [62]. PASTA was developed in Visual Basic [30]. These three systems are first come first served booking system, a triage booking system (high, medium, and low priority) where admission decision would be made at the time of patient assessment, and a waiting list system where patients are ordered according to a priority stratum and placed on a waiting list where operation slots are be assigned to the patients with highest priorities. The calculation of priority was based on the VF-14 questionnaire that includes visual acuity, ocular co-morbidity, and health related life quality (ability of independent life, mobility, activity restriction). The last two systems showed a significant reduction in wait times (30% to 60%) compared to the FCFS system.

A research was conducted to see the effects of ensuring a maximum duration of wait times for cataract surgery in Sweden [36]. The policy is called Maximum Waiting-time Guarantee (MWG). In this policy, the patients waiting for cataract surgery had the opportunity to choose another health authority for surgery if they had to wait for more than three months at the cost of the County Council. The research was done for two periods, one with guarantee and other without any guarantee. The patients were categorized into three groups based on urgency. The result shows that the median wait time was lesser in the guaranteed period than the non-guaranteed period, 89 days and 147 days respectively. In guaranteed period 51% of patients waited for less than three months, whereas in non-guaranteed period, 28% waited for less than three months. This research suggested that the guaranteed policy behaved as a priority tool for patients with most need and is an effective way to lessen the wait times of patients waiting for cataract surgery.

The priority calculation systems discussed in this section showed improvements in wait times of patients waited for surgery compared to the traditional FCFS policy. Different types of clinical and social criteria have been used to calculate priority of each patient. We did not find any research that developed or discussed any alternative methods to improve the wait time wait time 1 for patients.

3.3 Resource Scheduling/Capacity Planning

Another main reason for long wait times is the lack of hospital resources and improper use of the existing resources. Hospital resources can be of two types: physical resources (operating rooms, post-operative beds, beds for inpatients, and availability of these resources), and human resources (doctors, anesthesiologists, nurses and other staffs) [34, 47]. We found several papers that show how to maximize the use of the physical resources and estimates the need to increase budget. Proper use of doctors' time and better scheduling of them were also discussed.

Reindl et al. presented a discrete event simulation model, developed in SLX simulation package, that shows how to reduce patient wait times for cataract surgery, and how to increase OR utilization in a Germany hospital. The simulation model included the whole surgical procedure for cataract surgery beginning with the registration of patients in the hospital for surgery to the discharge of the patients after surgery. The simulation experiments showed that increasing the number of nurses could reduce patient wait times, and reducing the time between surgeries could lead to better OR utilization [56].

A research on the Ambulatory Care Unit, British Columbia Cancer Agency, found that resource utilization will improve if the followings are considered: i. late start of a clinic can have big impact on patient waiting because all the following appointments will be affected by the late start, and ii. presence of a resident doctor or a student causes more waiting [58]. These findings can be applicable to appointment with a specialist/surgeon.

A discrete event simulation model developed using Witness in 2004 showed the optimal use of an operation theatre by using weekly blocked booking scheduling for a hospital in Italy [59]. Experiments showed that the use of a master surgery schedule reduced the size of the waiting list and overruns. They also applied some other policies: (i) longest processing time first (LPT), longest operation first, that made the reduction of overtime; and (ii) the shortest processing time first (SPT), shortest operation first, that showed the increase in the number of completed operation.

Another simulation model, developed in Arena, was designed for the Capital District Health Authority of Halifax, Nova Scotia, that captures both wait time reduction and capacity planning. This model simulates three types of patients for general surgery: elective, non-elective, and non-surgery. This simulation model measures the minimum number of beds required for a hospital, and how long wait times depend on the use of beds, as surgeons keep their patients longer than expected by the Canadian Institute for Health Information (CIHI). After completing an operation, if no bed is free, a surgeon can shuffle the wait list and operate an outpatient if he has the time to do more operations [63].

A study was performed on eye cataract patients from the Northeast Service Delivery Area (NESDA) in British Columbia, where surgeries are performed by visiting surgeons because there are no permanent ophthalmologic services available [17]. The study aimed to understand the reasons influencing the outcome of cataract surgery. The result showed that patients have complications from the lack of regular follow up, lack of ophthalmologists, and long surgical wait list. This study also showed that the limited time dedicated to the OR, poorly equipped OR, and less experienced staffs lead the long wait times for patients and long wait list.

Arena was used to develop another simulation model to find the current efficiency and maximum capacity of a surgical suite in a hospital, and how the changes in resources affect the surgical suite performance [5]. Both inpatients and outpatients were considered in this research in order to simulate different elective surgeries. The total number of patients capable of being treated in a month was compared to the actual number of patients who received treatment in that hospital. To find the maximum capacity, the patients were kept entering the system till the end of the day.

The planning and management of bed capacity was discussed in [37] with respect to both bed occupancy and the rate of admission refusals, the simulation model was developed in Delphi environment. This model simulates the patient flow by means of beds in use. Bed occupancy was calculated using the following equation:

$$\text{bed occupancy} = (\text{number of bed days used}/\text{number of bed days available}) * 100\% \tag{3.6}$$

Refusal rate is related to bed occupancy because refusal happens when there is no available bed. Refusal rate = number of refused admissions/total number of referrals (or admissions+refusals) * 100%. The model showed the rate of refusal with respect to bed occupancy as both increases along with the increase in patient demand. This model was also used to forecast future bed requirements.

The operation theatre plays a very important role in the scheduling of surgery in a hospital. The accurate prediction of the duration of surgery helps in the optimal utilization of operation theatre, as a result more surgeries can be scheduled. Devi et al. developed a general framework to forecast surgery time in the Ophthalmology department of a hospital in order to schedule surgeries [24]. A number of variables were considered in this framework, such as, a patient's preconditions, the experience of the surgeon and anaesthetist, types of anaesthesia, patient's age, and the duration of surgery.

The key resources, identified in this section, that impact wait times are surgeon, nurse, and Operative Room (OR). Proper use of surgeons' time and proper scheduling of the existing ORs could improve wait times for patients.

3.4 Performance Metrics

Performance metrics are the criteria that are used to measure the behaviour of a system. Performance metrics show how well a system performs. We studied a survey paper that listed the most used performance metrics in this field by analysing over 100 research papers [14]. The most common used performance measure was the wait time of patients and surgeons. The long wait time of patients is the result of an imbalance in health care system. The wait times of surgeons indicate the workload of surgeons. The mean, median, mode, and standard deviation of the wait times were measured.

Resource utilization was the second most important measurement of performance metrics. The OR utilization has been a very good subject to research because optimal use of the OR can reduce patient wait times. Other resources like the number of surgeons, and other staff who help during surgery, utilization of the ward, and hospital beds were also discussed.

Patient scheduling was discussed by means of priority scoring system, patient deferrals, refusals, and cancellation of surgeries. Financial costs were discussed, in some of the research, in order to show the best case and worst case scenarios.

The literature survey shows that different approaches to reduce wait times and to make optimal use of the existing resources were used in this research field, such as, analytical study (mathematical programming), computer simulation and modeling, and case studies [15]. We observed that most of the papers focused on a specific hospital/clinic environment on a specific location. All hospitals/clinics environments are more or less different from each other because of their location, population demographics, budget, and infrastructure facilities. Since cataract surgery is an outpatient procedure and takes a short amount of time, most of the papers that directly talked on cataract surgery discussed about how to prioritize the patient wait list fairly, so that the patients receive treatment based on need. Most of the proposed simulators are not used in practice and are not publicly available. Thus filling the gap between reality and implementing the improvements into practice is very difficult [14].

3.5 Summary

In this chapter we have reviewed the available research papers related to cataract surgery wait times for patients. The papers are categorized into four groups. The major findings of each category is summarized in Table 3.1.

Table 3.1 presents a summary of our major findings in each category.

The Effects of Long Wait Times and Patient Dissatisfaction	**Scheduling of Patients/Wait List Scheduling**	**Resource Scheduling/Capacity Planning**	**Performance Metrics**
(i) High rate of fall. **(ii)** Increase possibility of other injuries. **(iii)** Loss of independent life style and dependence on others. **(iv)** Patient dissatisfaction.	**(i)** Different priority systems are used to schedule patients waiting for surgery (wait time 2) based on different clinical and social criteria. **(ii)** No discussion on how to reduce wait time 1.	**(i)** How to schedule the OR to get optimum utilization. **(ii)** Improper use of surgeons' time. **(iii)** Limited OR time dedicated for surgery. **(iv)** Longer use of hospital beds than expected.	Most used metrics are: **(i)** Mean wait times for patients. **(ii)** Mean wait times for surgeons. **(iii)** OR utilization. **(iv)** Utilization of hospital beds.

Table 3.1: Summary of Literature Survey

After reviewing the existing literature, we observed that there is no comprehensive simulator (built from scratch) that includes both patient and resource scheduling for cataract surgery. No simulator covered both wait time 1 and 2. We did not find any research that discuss about the alternative methods about how to refer patients from GPs to surgeons or developed a simulator for this. From these observations, we were interested in developing a discrete event simulation tool for cataract surgical procedure from scratch that will address the issues mentioned above. We chose to study this problem by developing a discrete event simulation tool since simulation has the ability to present a real system with different scenarios. It has also got huge acceptance in health care systems in order to evaluate the better performance of the system. We decided to build a simulation tool with the following features: wait time 1 and wait time 2 of patients, different patient referral methods, and scheduling of patient wait list and resources (surgeon and OR).

Chapter 4

The Proposed Simulator

This chapter discusses the structure of the proposed simulator. The simulator simulates the surgical procedure of Northern Health. This cataract surgical procedure has seven stages: (i) a patient's referral from her GP to a surgeon; (ii) first meeting with surgeon; (iii) decision of surgery; (iv) beginning of surgery; (v) end of surgery; (vi) post operative stay; and (vii) discharge from the hospital. A more generalised surgical procedure that overcomes the constraints of NH is also added to the simulator. Two proposed patient referral methods, OR scheduling and a patient priority scoring system are implemented in the simulator.

The main objective of using this simulator is to study the wait times of the patients throughout the surgical procedure. The simulator is simple and easy to use. The decision makers (health authority and government) can use this simulator to evaluate the performance of the surgical procedure for further improvement of the existing system.

The rest of the chapter is organised as follows: Section 4.1 overviews computer simulation and its classification, Section 4.2 is the description of the proposed simulation tool, and Section 5.4 concludes this chapter.

4.1 Simulation Overview

Computer simulation is a special purpose computer program that imitates a real world system [52]. This is a very powerful tool to model a system effectively. The system might be an existing or proposed system. This computer program is known as simulator and is sometimes referred to as simulation tool.

Simulation can be used for both development and analysis purposes. Some of the main uses are:

- It is widely used to understand the behaviour of an existing or proposed system.
- It is heavily used to conduct experiments to test the possible changes of a system.
- It is used to design complex systems which are very costly in real world.

Computer simulation is broadly classified based on how the state of the system is changed: continuous system and discrete system. In continuous simulation, the state variables of the system change continuously over time. If the state variables change only at discrete point of time then it is called discrete simulation [7].

Discrete simulation can be subdivided into two groups based on how the simulation time advances and how the system state is updated: time-stepped and event-driven simulation [46]. When the system state is updated at every time step, it is called a time-stepped simulation. Time step is a fixed interval of time at which the simulation clock is incremented. Whereas in event-driven simulation, the system state is updated only when an event occurs.

A discrete event simulation tool has the following main components: system, model, state, entity, attribute, event list, activity, and simulation clock [7]. For instance, in a single server system, the number of customers waiting or number of customers being served are the states of the system, the server and customers are the entities, customers' arrivals and departures are events, inter-arrival times and service times are the activities, and the state variables are updated based on the events in the system. The simulation starts when the simulation clock value is zero and continues until the end of the simulation time or the list of events becomes empty.

Nowadays, simulation is gaining more acceptance in the health care system because of its flexible representation of real systems. It considers different patient characteristics and shortage of resources [20]. Decision makers in the health care systems use discrete event simulation tools mainly for the following reasons: (i) to assess the effectiveness of the present system using 'what-if'; (ii) to investigate resource management and increased patient flow; and (iii) to compare different models. Their target is to reform the existing system for better performance [41].

4.2 The Cataract Surgical Procedure Simulator

The proposed cataract surgical procedure simulator is designed to implement the procedure of cataract surgery starting from the referral of a patient from a GP to the discharge of the patient from the hospital after the surgery is completed. The simulator is developed in JAVA on NetBeans IDE 8.0.1. The simulator follows a discrete event simulation method since the simulation clock advances time to the next event only. Patient and surgeon are the two entities used in this simulation. The simulation process has the following events:

- Patient referral time from GP
- First meeting begins with surgeon
- First meeting ends with surgeon
- Decision of surgery
- Surgery begins
- Surgery ends

- Discharge from hospital

Whenever an event occurs the system's state is updated. All the seven events are designed as seven state update methods.

The diagram in fig. 4.1 shows the structure of the proposed simulator with its components.

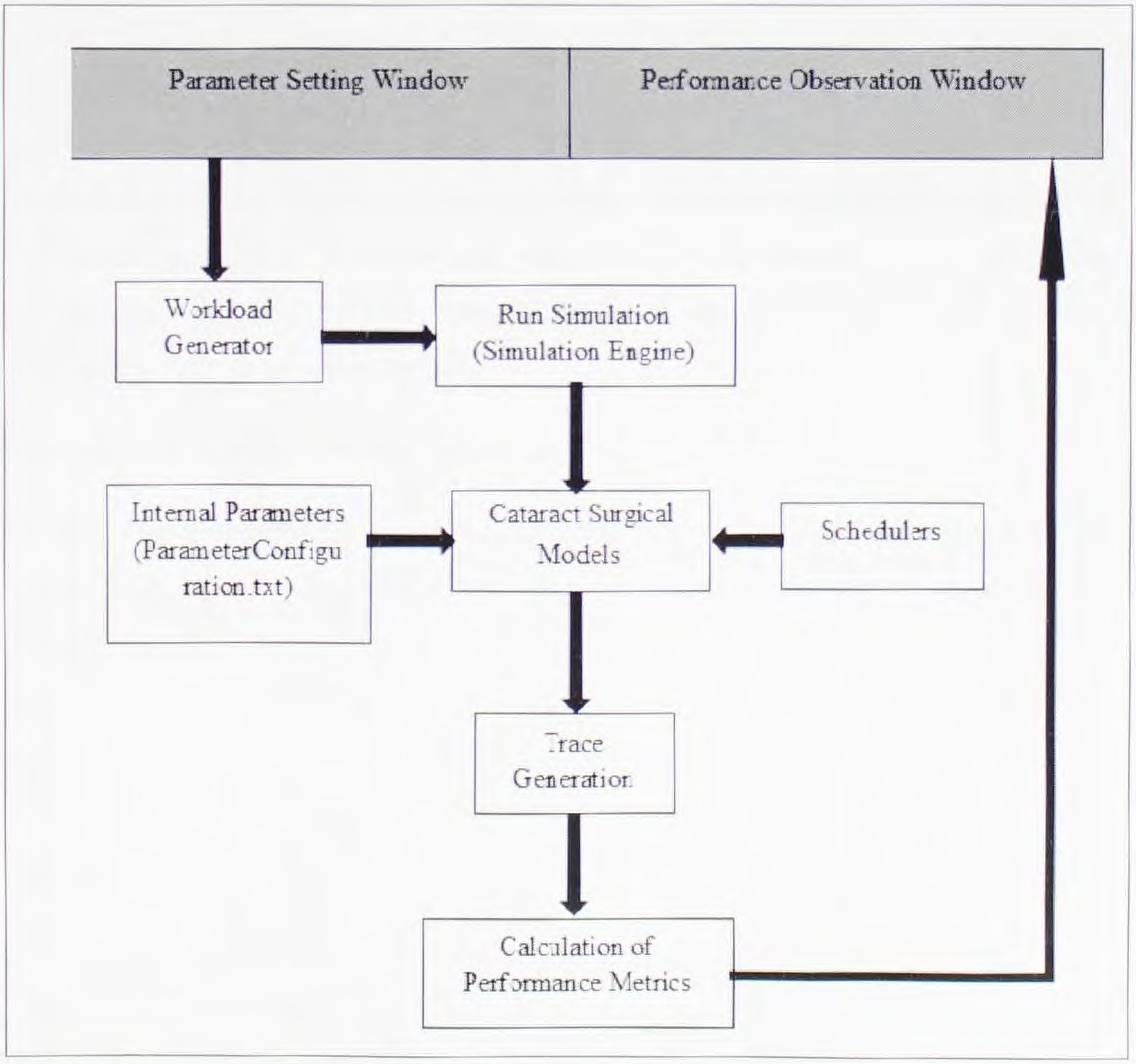

Figure 4.1: Structure of the Proposed Simulator

The simulator has eight major components: Graphical User Interface (GUI) (the gray boxes), workload generator, simulation engine, cataract surgical model, internal parameters, schedulers, trace generation, and calculation of performance metrics. The working procedure of each component is described below one after another.

4.2.1 Graphical User Interface (GUI) of the Simulator

The simulator starts with a Graphical User Interface. The gray boxes in fig. 4.1 show the GUI part of the simulator. It has a main menu with two buttons: 'Parameter Setting Window' and 'Performance Observation Window'. These buttons display two individual windows if they are clicked. The user first clicks the Parameter Setting Window button, the window appears, and the user sets values of the parameters to run the simulation. Then the user clicks the Performance Observation Window button which displays the performance metrics in another window. Description of these two windows are given below.

4.2.1.1 Parameter Setting Window

The Parameter Setting Window allows the user to set the parameters that are used by the simulator as inputs to run simulation. The screen shot of this window is shown in fig 4.2.

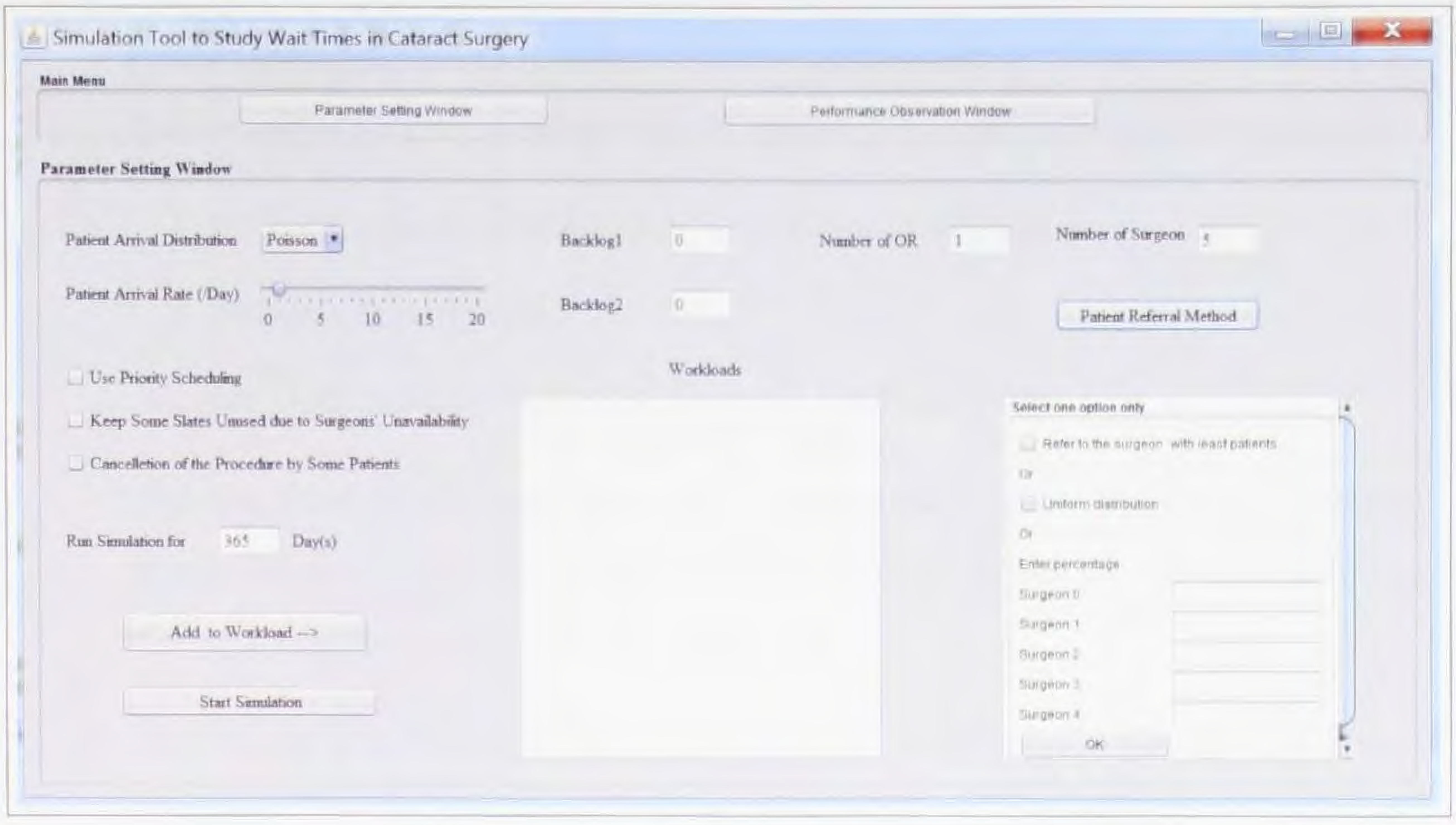

Figure 4.2: Parameter Setting Window of the Simulator

The parameters are listed below.

- Patient Arrival Rate/Day: The user has to choose a value between the range one to twenty. By default the value is set as one.
- Patient Arrival Distribution: The user can choose either Poisson or Normal distribution.
- Number of ORs: Any number of OR(s) can be set here. The default value is one.
- Number of Surgeons: Any number of surgeon(s) can be set here. The default value is five.
- Backlog1: Any number of backlog patients can be set here. The default value is zero.
- Backlog2: Any number of backlog patients can be set here. The default value is zero.

- Patient Referral Method: A sub-window will appear with three options when this button is clicked. The user has to choose one of the following three options:

  i Refer to a Surgeon With the Least Number of Patients.

  ii Uniform Distribution.

  iii Set Different Percentages of Patients for Each Surgeon.

  The user must choose one option only. In case she forgets to choose an option, or chooses more than one option, a message will be displayed with a request to choose an option, or choose one option only.

- Use Priority Scheduling: If the user checks this input box, the simulator will use Manitoba Cataract Wait List Program (MCWLP) priority scheduling to choose the next patient for surgery, otherwise FCFS policy is used.

- Keep Some Slates Unused Due to Surgeons' Unavailability: If the user checks this input box, the simulator will keep some slates unused for each surgeon. The number of slates that will remain unused is set as the value of an internal parameter.

- Cancellation of the Procedure by Some Patients: If this input box is checked, the simulator will take some patients out of the surgical procedure either at wait time 1 or wait time 2. The number of patients who will cancel the procedure is set as the value of an internal parameter.

- Simulation Days: The simulation will run from day one up to the days entered as input. If the user runs the simulation for more than one year, the patient arrival rate/day, given as input, will be increased by one for each next year. This is done because the population demography says that the patient arrival rate is going to increase in every coming year.

After setting the values of these parameters, the user has to add the input set as a workload by clicking the button 'Add Workload'. Any number of workloads can be added. All workloads are shown as a list in the 'Workloads' area, such as, workload0, workload1, and workload2. After adding all the workloads, the user has to click the button 'Run simulation' to start the simulation. The simulator displays the message, "Surgical procedure is complete", that means the simulation is done.

4.2.1.2 Performance Observation Window

This window allows the user to view the performance of the simulated surgical models for each workload. It also allows to compare the performances among different workloads. Fig. 4.3 shows a screen shot of this window.

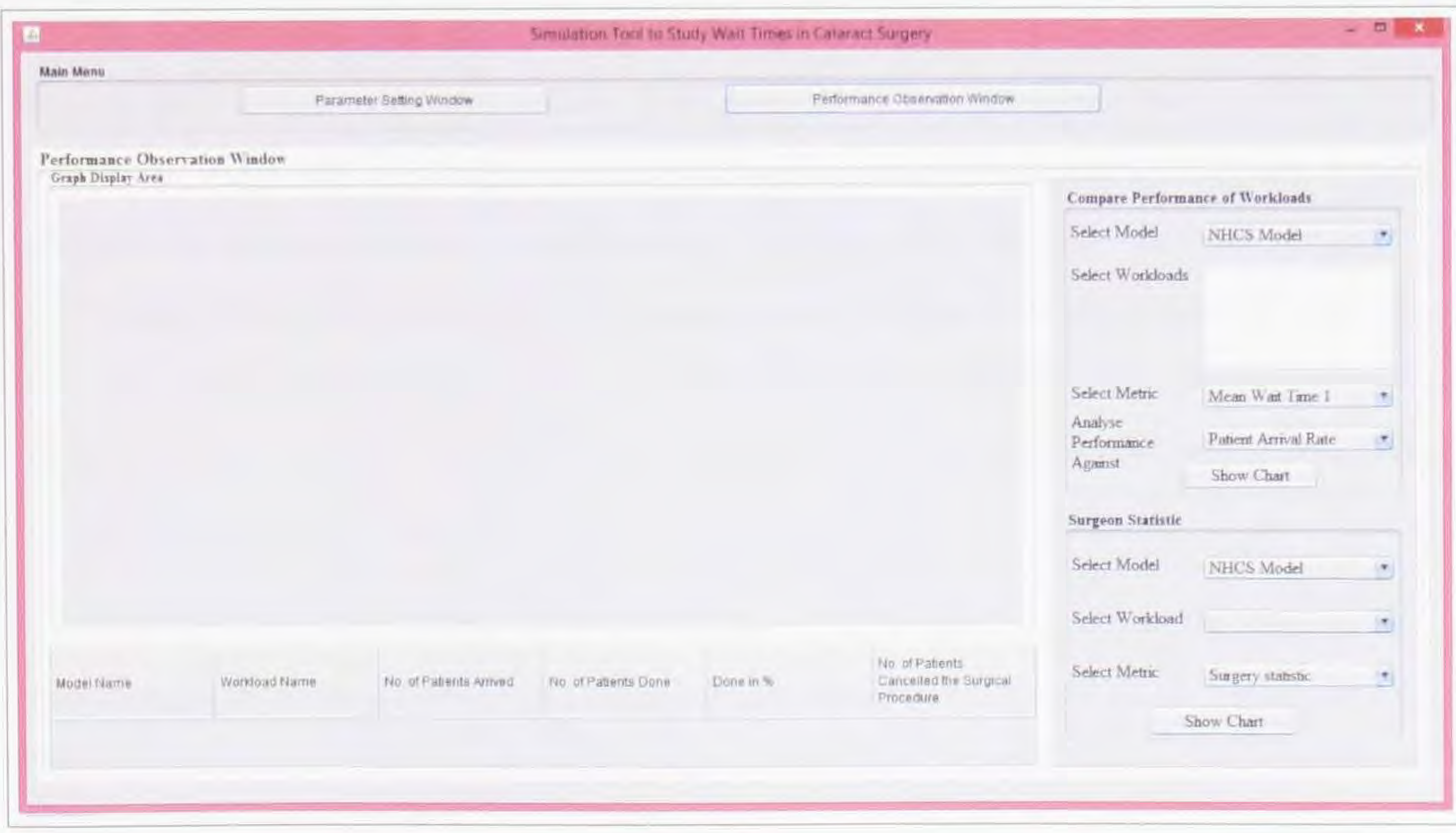

Figure 4.3: Performance Observation Window of the Simulator

There are two sub menus and a table in this window. The upper right sub menu 'Compare Performance of Workloads' shows performance metrics of one or more workloads. The following metrics are displayed by means of graphs: (i) mean wait time 1; (ii) mean wait time 2; (iii) wait time 1 distribution; (iv) wait time 2 distribution; and (v) OR utilization. The graphs are used to compare the performance of different workloads. First the user has to select a model name; either NHCS model or CSG model (these two models are explained in subsection 4.2.5). Next the user selects workloads (one, multiple, or all) from the list of workloads displayed. Then the user selects the performance metric desired. Next the user chooses the parameter against what the performance would be analysed. There are eight parameters to check performance against: (i) patient arrival rate; (ii) backlog patients; (iii) patient referral method; (iv) no. of surgeons; (v) no. of ORs; (vi) priority scheduling; (vii) unused slates of surgeons; and (viii) cancellation of the procedure by patients. Finally, the user clicks the 'Show Chart' button to see the result in terms of a graphical chart.

The lower right sub menu 'Surgeon Statistic' displays statistics about patients and surgery of all surgeons. It has three graphs. The user again has to select the model and workload names in order to see the surgeons' information. The first graph shows how many surgeries are performed, pending and cancelled for each surgeon. The mean wait time 1 and 2 of each surgeon are displayed in the second graph. In the last graph, the number of unused slates for each surgeon is displayed. All the graphs will be appeared in the 'Graph Display Area', located in the upper left side of the main window.

The left lower side table shows the summary of surgical procedure for each workload run in the simulation. It has six columns: Model Name, Workload Name, Number of Patients Arrived, Number of Patients Done, % of Patients Done, and Number of Patients Cancelled the Procedure. This table keeps a record of the above information by workload and model names.

4.2.2 Internal Parameters

There are several internal parameters that are used by the simulator to execute the simulation. These parameters are configured with preset constant values for the whole simulation period. The parameter names are listed as follows:

1. percentageOfSurgeryCancelledByPatient

2. percentageOfFirstMeetingCancelledByPatient

3. totalDaysOfSurgeryCancelledBySurgeonDueToUnavailability

4. targetWaitTime2

5. surgeryDuration

6. surgeryPreparationTime

7. firstMeetingDuration

8. patientVisitIntervalForSurgeon

9. patientVisitDurationPerDayForASurgeon

10. blockedORTimePerDayForASurgeon

11. maxNoOfSurgeryDaysForEachSurgeonOnEachWeekForCSGM

12. decisionDayOfSurgery

13. postOperativeStay

The parameters' values and how they are chosen is explained in the next chapter (subsection 5.1.1). All these parameters are saved in a text file named 'Parameter-Configuration', so that the user can change the values easily if it is needed.

4.2.3 Workload Generator

A workload generator is implemented in order to generate the workloads that are used in the simulator. A workload is the combination of the values of the input parameters. Each workload represents a scenario of the surgical procedure. Any number of workloads can be generated, based on the different combination of the input parameters. The workloads are referred by workload Id, for example, Workload0, Workload1 and so on. All workloads are run in parallel in the simulator.

The input to each workload is the set of values entered in all input parameters. The output of each workload is the Id of each patient, the GP referral time for each patient, and the Id of the surgeon to whom the patient is referred. Here the patients are referred to the surgeons by following a patient referral method (mentioned in the Parameter Setting Window subsection). The first method, refer patients to the surgeon with the least number of patients, refers patients to the surgeon who has the least number of patients. In this method, whenever a new patient enters in the system, the simulator checks the number of patients of every surgeon till that day and refers that patient to the surgeon who has least number of patients. In the second method, uniform distribution, patients are referred equally to all surgeons. For example, if there are three surgeons, the first patient will be referred to surgeon 0, second patient to surgeon 1, third patient to surgeon 2, and then fourth patient to surgeon 0 again and so on. In the last method, different percentages of patients for each surgeon, surgeons will receive referred patients based on the given input percentages. The patients are referred to all surgeons in a round robin fashion until the given percentage of patients for each surgeon is filled up.

The purpose of generating different workloads is to include different possible scenarios of the surgical procedure in a single simulation run. This will allow the user to compare the results of different scenarios.

4.2.4 Simulation Engine

The simulation engine controls the simulation process. It has a simulation clock that keeps track of the current simulation time. We consider one simulation clock tick is equal to one minute. The user enters input in 'Run Simulation Days' in actual days such as 365 days or 700 days. The simulation engine converts the actual time into simulation clock time units and runs the simulation.

The simulation engine drives the cataract surgical models that are simulated in this simulator. The logic of the event handling for each model is given below.

Algorithm 4.1 Event Logic of the Simulator

Ensure: $currentDay \leftarrow 1$, $patientList \leftarrow$ holds all the patients

```
while currentDay <= finalSimulationDay
  set startSimClockOfTheDay to the beginning of the currentDay
  set endSimClockOfADay to the end of the currentDay
  while startSimClockOfTheDay <= endSimClockOfADay
    get patient from the patientList
    if patientArrivalTime == startSimClockOfTheDay
      call gpRefer()
    else if patientGPReferalTime < startSimClockOfTheDay
      call firstMeetingBegin()
    else if patientMeetingEndTime == startSimClockOfTheDay
      call firstMeetingEnd()
    else if patient is waiting for decision
      call decision()
    else if patientDecision < startSimClockOfTheDay
      call surgeryBegin()
    else if patientSurgeryBegin == startSimClockOfTheDay
      call surgeryEnd()
    else {patient's surgeryEnd<startSimClockOfTheDay}
      call discharge()
    end if
    update patientList
    increment startSimClockOfTheDay
  end while
  increment currentDay
  if day is last week day
    set currentDay to the beginning of the next week day
  end if
end while
Trace file is written
```

Each state update method does its calculation based on the values of the internal parameters from the ParameterConfiguration.txt file, such as, surgery duration is 30 minutes, post operative stay is 15 minutes etc. The *patientList* is used to write the trace file. After updating the status of each patient, the updated states are added to the trace, and the *patienList* is also updated accordingly.

4.2.5 Cataract Surgical Models

The cataract surgical models are designed to execute the surgical procedure. To simulate the cataract surgical procedure, we followed the procedure that is shown in fig. 2.1. Two surgical models are implemented:

- Northern Health Cataract Surgical Model (NHCS Model)
- Cataract Surgery Generic Model (CSG Model)

The first model, NHCS model, follows the current surgical procedure of Northern Health. The second model, CSG model, is a more generalized model that overcomes the constraints observed in the NH procedure, such as, more than one ORs might be allocated for surgery, more than one surgeon might perform surgery on the same day based on the number of the allocated ORs, and a surgeon might perform surgery in more than one week day. These two models use different scheduling policies in order to allocate the OR(s) among the surgeons.

The NHCS model is simulated first to observe the current situation of Northern Health with possible scenarios. Then the CSG model is added to the simulation tool in order to see how much this would improve the system performance. Both surgical procedural models are executed parallely in the simulator. Each surgical model is used to execute the surgical procedure for the total simulation period. The working procedure of the surgical models is stated below.

When the user runs the simulator, the surgical procedure models start working after the workload generation is done. Once the patient generation is done, all the patients enter into a common queue. Each surgical model receives patients one after another from the common queue with patient id, surgeon id, GP referral time, and present status (waiting for first meeting, waiting for surgery, or waiting for discharge). On each week day, each surgical model receives information, from the respective OR scheduler, about the surgeon to whom the OR is scheduled for surgery. Two things can happen on each day:

- The surgeon, to whom the OR is scheduled on that day, will perform zero, one or more surgeries based on the number of patients already waiting in the queue. The surgeon will perform surgery following FCFS scheduling or Manitoba Cataract Waiting List Program (MCWLP) priority system (based on the given input) for the time allocated for surgery.
- Other surgeons, who are not scheduled for surgery on that day, meet zero, one or more patients based on the number of patients already waiting in the queue for first meeting with surgeon. The surgeons will visit patients on FCFS basis for the time allocated for patients visit. In a patient meeting, necessary tests are done and after making decision to undergo surgery, the patient's information is entered into the OR booking office on the same day, and the patient starts waiting for surgery.

If the day is weekend, then nothing will happen that day. The simulation clock will be advanced to the beginning of the next week.

If the system has either backlog 1 or 2 or both, the surgeons will meet backlog patients or perform surgery for the backlogged patients first following the same OR scheduling policy. All backlog patients are equally distributed to all surgeons in this simulator. This is done for simplicity as their actual distribution is unknown. Although this does not happen in reality. So this uniform distribution of backlog patients will understate the simulated mean wait times for patients.

Throughout the simulation process, some patients will be removed from the procedure randomly from either wait time 1 or 2 based on the given input in the ParameterConfiguration file (if the input option 'Cancellation of the Procedure by Some Patients' in the Parameter Setting Window is checked). As we already mentioned some patients take themselves out from the surgical procedure either in wait time 1 or wait time 2 due to long wait or for other reasons. Some operation slates of each surgeon will remain unused randomly (if the input option 'Keep Some Slates Unused Due to Surgeons' Unavailability' is checked). We already discussed the reason of this, as sometimes surgeons go on vacation or attend conference with short notice and due to lack of coordination their slates remain unused.

Throughout the execution of the surgical models, whenever an event occurs (for example, a patient's surgery begins, and surgery ends), the system's states are updated and finally saved in a trace file for each workload.

4.2.6 Schedulers

Three different schedulers are simulated in this simulator: NHCSM scheduler, CSGM scheduler, and priority scheduler. The first two schedulers are used to simulate the OR scheduling for NHCS model and CSG model respectively. The third scheduler schedules patients waiting for surgery based on priority. This scheduling policy is used by both models. We already discussed these scheduling policies in Chapter 2. The implementation of these schedulers are explained below.

NHCSM Scheduler: This scheduling policy has two restrictions: (i) each day only one OR, allocated for cataract surgery, is assigned to a surgeon only in a round robin fashion; and (ii) each surgeon performs surgery one day only a week. This scheduling policy is derived in algorithm 4.2.

Algorithm 4.2 OR Scheduling for Northern Health Cataract Surgery Model

Require: List of variables:

$numberOfSurgeon$

$surgeonId$

day

$totalDays$

$weekDayCount$

Ensure: Initialization of variables:

$surgeonId \leftarrow 0$

$weekDayCount \leftarrow 0$

$day \leftarrow 0$

while $day < totalDays$
  increment day
  increment $countWeekDay$
  $surgeonId$ gets the OR
  if $numberOfSurgeon < 5$ and $countWeekDay = numberOfSurgeon$ {checks if number of surgeon is less than 5 and all surgeons have got access to the OR}
    $day \leftarrow day + (5 - numberOfSurgeon) + 2$ {skips the other week days, the OR will be remain unused those week days}
    $countWeekDay \leftarrow 0$
  end if
  if $countWeekDay == 5$ {checks if the day is last week day}
    $day \leftarrow day + 2$ {advances the day to the last day of the week}
    $countWeekDay \leftarrow 0$
  end if
  increment $surgeonId$
  if $surgeonId == numberOfSurgeon$
    $surgeonId \leftarrow 0$
  end if
end while

If there are more than five surgeons, based on the algorithm, not every surgeon will get access to the OR in every week since there is only one OR and five week days. If there are less than five surgeons, the OR will remain unused other week days after each surgeon gets access to the OR. We have drawn two tables, for example, table 4.1 and table 4.2, to show the OR scheduled days for surgery with one OR for four and seven surgeons. Here, surgeon Id starts with S0. sd and pm indicate surgery day and patient meeting day respectively. Nothing happens on the weekend. According to the algorithm, the OR is assigned to surgeon S0 on Monday, surgeon S1 to Tuesday and so on based on the number of surgeons.

	S0	S1	S2	S3
Day 1 Monday	**sd**	pm	pm	pm
Day 2 Tuesday	pm	**sd**	pm	pm
Day 3 Wednesday	pm	pm	**sd**	pm
Day 4 Thursday	pm	pm	pm	**sd**
Day 5 Friday	pm	pm	pm	pm
Day 6 Saturday				
Day 7 Sunday				
Day 8 Monday	**sd**	pm	pm	pm
Day 9 Tuesday	pm	**sd**	pm	pm
Day 10 Wednesday	pm	pm	**sd**	pm

Table 4.1: OR Scheduled Days for Surgery for Four Surgeons (for Northern Health Cataract Surgical Model)

	S0	S1	S2	S3	S4	S5	S6
Day 1 Monday	**sd**	pm	pm	pm	pm	pm	pm
Day 2 Tuesday	pm	**sd**	pm	pm	pm	pm	pm
Day 3 Wednesday	pm	pm	**sd**	pm	pm	pm	pm
Day 4 Thursday	pm	pm	pm	**sd**	pm	pm	pm
Day 5 Friday	pm	pm	pm	pm	**sd**	pm	pm
Day 6 Saturday							
Day 7 Sunday							
Day 8 Monday	pm	pm	pm	pm	pm	**sd**	pm
Day 9 Tuesday	pm	pm	pm	pm	pm	pm	**sd**
Day 10 Wednesday	**sd**	pm	pm	pm	pm	pm	pm

Table 4.2: OR Scheduled Days for Surgery for Seven Surgeons (for Northern Health Cataract Surgical model)

CSGM Scheduler: In this scheduling approach, the number of surgeons who will perform surgery each day depends on the number of the allocated ORs for surgery. We assume that, in this scheduling, each surgeon performs surgery maximum two days a week. This scheduling policy is implemented following the algorithm 4.3. We assume that first day is Monday.

Algorithm 4.3 OR scheduling for Cataract Surgery Generic Model

Require: List of variables:

$numberOfOR$, $numberOfSurgeon$, $surgeonId$

day, $totalDays$, $weekDayCount$

$surgeryDayCounterForEachSurgeon[numberOfSurgeon]$

$surgeonNumberCounter$

Ensure: Initialization of variables:

$surgeonId \leftarrow 0$

$day \leftarrow 0$, $weekDayCount \leftarrow 0$

$surgeryDayCounterForEachSurgeon[numberOfSurgeon] \leftarrow 0$

while $day < totalDays$
  increment day
  increment $weekDayCount$
  $surgeonNumberCounter \leftarrow 0$
  while $surgeonNumberCounter < numberOfOR$
    if $surgeryDayCounterForEachSurgeon[surgeonId] < 2$ {each surgeon performs surgery maximum two days a week}
      $surgeonId$ gets an OR
      $surgeryDayCounterForEachSurgeon[surgeonId]++$
      $surgeonNumberCounter++$
    end if
    increment $surgeonId$
    if $surgeonId == numberOfSurgeon$
      $surgeonId \leftarrow 0$
    end if
  end while
  if $weekDayCount == 5$ {checks if the day is last week day}
    $day \leftarrow day + 2$ {advances day to the last day of the week}
    $weekDayCount \leftarrow 0$
  end if
end while

An example table (Table 4.3) is drawn to show scheduled dates of ORs for surgeons according to the generic algorithm where number of ORs is three, number of surgeons is seven, and total time is ten days. According to the algorithm, the three ORs, on the first week day, will be assigned to the first three surgeons, S0, S1, and S2, other surgeons will meet patients that day. On the second day, surgeons S3, S4, and S5 will get access to the ORs for surgery. The ORs will be assigned to surgeons S6 and, S0 and S1 again on the third day. In this way, the surgeons have to wait for their turn in a circular way to use the available ORs for surgery.

	S0	S1	S2	S3	S4	S5	S6
Day 1 Monday	**sd**	**sd**	**sd**	pm	pm	pm	pm
Day 2 Tuesday	pm	pm	pm	**sd**	**sd**	**sd**	pm
Day 3 Wednesday	**sd**	**sd**	pm	pm	pm	pm	**sd**
Day 4 Thursday	pm	pm	**sd**	**sd**	**sd**	pm	pm
Day 5 Friday	pm	pm	pm	pm	pm	**sd**	**sd**
Day 6 Saturday							
Day 7 Sunday							
Day 8 Monday	**sd**	**sd**	**sd**	pm	pm	pm	pm
Day 9 Tuesday	pm	pm	pm	**sd**	**sd**	**sd**	pm
Day 10 Wednesday	**sd**	**sd**	pm	pm	pm	pm	**sd**

Table 4.3: OR Scheduled Days for Surgery for Seven Surgeons when the Number of ORs is Three (for Cataract Surgery Generic Model)

Priority Scheduler: In the priority scheduler, the Manitoba Cataract Waiting List Program (MCWLP) priority system is used to calculate the priority of each patient. So far, Northern British Columbia has not used any priority system in order to serve the right patient (patient based on urgency) first. We chose this priority system because,

- It is the first cataract patient wait list prioritizing provincial program in Canada
- It has shown a higher level of equality as all patients are prioritized by the same criteria.

We did not incorporate emergent patients because there is almost no emergency case in cataract surgery. Equation 3.2 has been used to calculate priority for each patient. The priority scheduler calculates the priority of each patient randomly as we don't have real information about the urgency score of the patients. The priority of each patient (already waiting in the wait list) of the surgeon is updated at the beginning of each day using the priority scheduler. The patients with highest priorities then go for surgery one after another.

4.2.7 Trace Generation

Trace files are used as the base for the calculation of the performance metrics. The state variables are saved as trace in individual files for each workload of each surgical model. For example, if there are two models and three workloads, six trace files will be generated. Each trace file is saved by the respective surgical model name followed by the workload number, for example NHCSMTraceList0, CSGMTraceList0, etc. Traces are written in simulation clock units. Each trace file is a collection of sets of values about the state of the patients.

Each set of a trace has the following data: patient Id (pId), surgeon Id (sId), GP referral time (gpRefer), first meeting with surgeon begin time (firstMeetingBegin), first meeting end time (firstMeetingEnd), decision of surgery time (decisionOfSurgery), surgery begin time (surgeryBegins), surgery end time (surgeryEnds), and discharge time (discharge). Patient Id starts with one. Surgeon Id starts with zero. All the times are saved in simulation clock units. A value of -1.0 indicates that either a first visit with a surgeon or a surgery is cancelled by a patient. A value of 0 means that the simulation run time is over, so the patient's surgical procedure is incomplete and the patient is waiting at some stage. The collection of the sets of values is saved according to patient Id. A sample trace is given below for 10 patients, where the number of surgeon is three.

pId, sId, gpRefer, firstMeetingBegin, firstMeetingEnd, decisionOfSurgery, surgeryBegin, surgeryEnd, discharge

1,0,11.0,180.0,220.0,221.0,555.0,585.0,600.0

2,1,17.0,360.0,400.0,401.0,735.0,765.0,780.0

3,2,18.0,180.0,220.0,221.0,375.0,405.0,420.0

4,0,183.0,360.0,400.0,401.0,600.0,630.0,645.0

5,1,187.0,405.0,445.0,446.0,780.0,810.0,825.0

6,2,194.0,540.0,580.0,581.0,0.0,0.0,0.0

7,0,201.0,405.0,445.0,446.0,645.0,675.0,690.0

8,1,206.0,450.0,490.0,491.0,-1.0,-1.0,-1.0

9,2,215.0,585.0,625.0,626.0,0.0,0.0,0.0

10,0,369.0,720.0,760.0,761.0,0.0,0.0,0.0

4.2.8 Calculation of Performance Metrics

The performance calculation engine reads the respective trace file, performs required calculations, and converts the results from the simulation time units to the actual times. The result of the calculation is sent to the 'Performance Observation Window', where it is displayed as a graphical chart. The backlog patients are not included in the calculation of performance metrics, because, it is not certain when they started waiting for first meeting with surgeon or for the surgery. Exclusion of backlog patients' wait times in the calculation of performance metrics would understate the simulated mean wait times. The mean wait times would be more worse if the backlog patients' are added. The following performance metrics are calculated.

1. **Mean Wait Time 1:** Mean wait time 1 is the mean wait times of the patients between GP referral and first meeting with surgeon. Standard deviation, and median are calculated along with this mean wait.

2. **Mean Wait Time 2:** This metric shows mean wait time of the patients done with surgery along with standard deviation, and median. This wait duration is from the decision day of surgery to the day the surgery is performed. Mean wait time 2 is the most commonly used performance measure in this research field.

3. **Wait Time 1 Distribution:** This metric calculates the duration of the wait times for the patients in weeks for wait time 1 in terms of patient percentages. It shows the percentages of patients who waited for one week, two weeks, up to the final simulation week.

4. **Wait Time 2 Distribution:** This metric calculates the duration of wait of patients in weeks for wait time 2 in terms of patient percentages. It shows the percentages of patients who waited for one week, two weeks, up to the final simulation week. Since both the federal and provincial governments' target is to complete 90% of the cataract surgeries within 16 weeks, this metric gives a clear idea about how far the cataract surgical procedure models are from the target.

5. **OR Utilization:** The optimum use of ORs is another important issue in performing more surgeries, if more surgeries are performed, the wait times will be reduced and the result will be higher patient satisfaction. OR utilization is shown in percentage. It is calculated as follows:

$$\begin{aligned} \text{OR Utilization} = (&\text{total number of surgeries actually performed} \\ &/\text{total number of surgeries should be performed}) * 100 \end{aligned} \tag{4.1}$$

The following metrics are calculated to show individual surgeon's statistic about patients and surgery.

1. **Mean Wait Time of Each Surgeon:** This metric shows the mean wait times 1 and 2 of individual surgeon. This metric gives a chance to the patients and GPs to choose a surgeon with less wait times.

2. **Surgery Statistic of Each Surgeon:** This metric includes the number of surgeries performed, pending, and cancelled by each surgeon. This information provides a picture of a surgeon's workload and business.

3. **Unused Slates of Each Surgeon:** Total number of unused slates of each surgeon is presented in this graph. This metric is related to the total number of surgeries and mean wait time 2. This metric is included to show that unused slates result in longer wait time and lesser number of surgeries.

Summary of the Surgical Procedure: A summary table is included that shows the following information: how many patients arrived, how many patients underwent surgery (in number and in percent), and how many patients cancelled the procedure either at wait time 1 or 2. We get a whole picture of the surgical procedure from this table.

4.3 Summary

In this chapter we have discussed the structure of the proposed simulator with its components. We started with the simulation technique used in this thesis. The two OR scheduling policies are explained with algorithms and examples. The list of performance metrics that are included in the simulator in order to evaluate the system performance is also included.

Chapter 5

Simulation Study

In this chapter, we present the simulation experiments that we conducted, and the observations. In this simulation study, we are interested in observing the changes (increase or decrease) in the wait times of patients, percentages of total surgeries performed, and OR utilization. The experiments also illustrate the functionality and use of the simulator. We have done two sets of experiments for the two cataract surgical models: NHCS model and CSG model. We have included different scenarios of the surgical procedure in order to conduct experiments.

Before starting the experiments, we would like to recall the research questions we posed in the Chapter Introduction, because that were the main motivation behind conducting the experiments:

1. How to reduce wait times of patients?
2. What is the impact of the patient list size (both current and backlog patients) on wait times and total surgery done?
3. If NH does not increase resource or change scheduling, what will be the performance of the surgical procedure in the future?
4. How accurate is the simulator to produce historical outcomes?

5. What are the main factors that cause long wait times?

6. How much more resources does the NH need to meet the target wait time?

Throughout the simulation experiments, we try to answer these research questions. We have categorised the experiments based on the objective of each research question. The first research question brings two scenarios: (i) how to reduce wait times of patients with current resources? and (ii) how much the wait times are reduced with increased resources? Two different sets of experiments are done to find out the answers. The second research question focuses on the size of the patient wait list or patient population, because, the size of the patient list plays an important role in total number of surgeries done and in wait times. We know the longer the patient wait list, the more the wait time is. Three experiments are done therefore to answer this question. The third research question indicates the future situation of NH with the present surgical procedure. We try to find the answer to this question from the experiments done for the second research question. The fourth research question indicates the accuracy of the simulator; how close or accurate is the simulated output compared to the historical data of the NH cataract surgical procedure? This question is answered by comparing the simulated output of an experiment with the historical output of the NH. We try to answer the last two research questions, after conducting all experiments. Because, after conducting all the experiments, we try to come to a decision regarding which factors result in long wait times and which do not; and we try to establish how much more resources are needed to meet the target by NH.

At first we present the experiments for NHCS model. We have done this simulation study as case study.

5.1 Experiment for Northern Health Cataract Surgical Model

The NHCS model follows the cataract surgical procedure of the University Hospital of Northern British Columbia (UHNBC) of Northern Health authority. At present they have five surgeons to perform cataract surgery, one OR available for this surgery, where the OR is assigned to a surgeon only for three hours (8 AM to 11 AM) every week day in the morning. Each day four to five surgeries are performed. A surgeon, after completing every surgery, has to wait to get the OR ready again by the staffs before doing the next surgery. We have used this information as parameters' values to conduct experiments.

The experiments for this model are conducted and grouped according to the categories that we discussed above already. The following metrics are calculated as output for the experiments: (i) percentages of total surgeries performed; (ii) mean wait time 1; (iii) wait time 1 distribution; (iv) mean wait time 2; (v) wait time 2 distribution; and (vi) OR utilization. Before we begin the experiments, the simulation parameters and the internal parameters, used for this simulation study, and their values are explained below.

5.1.1 Simulation Setup

The simulation parameters for this study and their values are given in table 5.1.

Parameter	**Value**
Patient Arrival Distribution	Poisson
Patient Arrival Rate/Day	3-10
Patient Referral Method	i. Send patient to surgeon with least patients, ii. uniform distribution, and iii. different percentage to different surgeons
Number of OR	1-2
number of Surgeon	4-10
Backlog1	0 and 250
Backlog2	0 and 250
Priority Scheduling	yes and no
Procedure Cancelled by Patients	yes and no
Unused Slates by Surgeons	yes and no
Run Simulation for	365 days

Table 5.1: Simulation Parameters and Their Values Used for Northern Health Cataract Surgical Model

Besides these input parameters, there are a number of internal parameters that are saved in a text file with default values to be used by the simulator to run the simulation. Some parameters' values are taken from the available historical data of NH, some are from the discussion with NH authority which are not available in historical record, and the rest are set randomly as we did not receive any information about those. The internal parameters and their values used for the experiments are shown in the table 5.2.

Internal Parameter Name	Value
Following values are collected from historical data	
Percentage of surgery cancelled by patients	6%
Percentage of first meeting cancelled by patients	6%
Following values are set based on the discussion with NH authority	
First meeting duration	40 minutes
Patient visit interval for surgeon	5 minutes
Patient visit duration per day for a surgeon	3 hours
Blocked OR time per day for a surgeon	3 hours
Decision day of surgery	Same day of first meeting
Surgery preparation time	15 minutes
Post operative stay	15 minutes
Surgery duration	30 minutes (Due to long wait of the patient, the cataract gets developed fully and hence it takes more time to remove it than its normal time (20 to 25 minutes))
Following values are set randomly	
Total days of surgery cancelled by surgeon due to unavailability	3 days a year

Table 5.2: Internal Parameters and Their Values Used for Simulation Experiments.

Finding suitable values for the input parameters and the internal parameters was one of the important aspects of the simulation process. That is why we analysed historical data from UHNBC of NH (from 2008 to 2012 (up to July)) about cataract surgery so that we can observe the pattern of the data from which we derive values to some simulation parameters. Another objective of collecting this data is to compare the simulation result with the data to illustrate the accuracy of the proposed simulator.

We made a summary of the data (fig. 5.1) from the historical record that was received in two different spreadsheet formats (in 2012 and 2014).

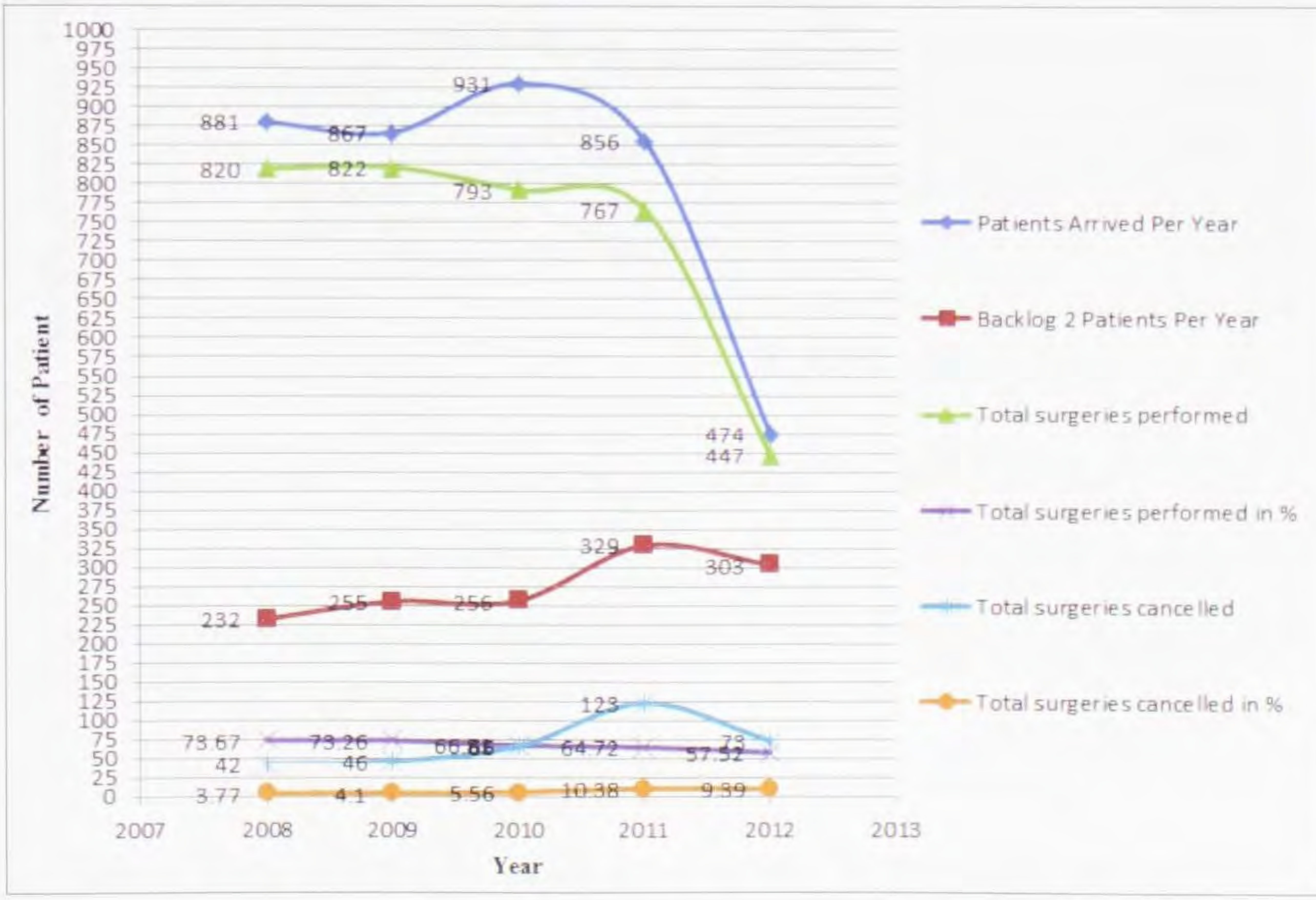

Figure 5.1: Total Number of Patients Arrived, Total Number of Surgeries Performed and Total Number of Surgeries Cancelled by Patients in Northern Health (2008-2012 July)

It is clearly seen in the graph that due to long wait times, NH had more backlog 2 patients in comparison to each previous year. Furthermore the percentage of surgeries was lower compared to the previous years. The percentage of cancelled surgeries performed by patients was increased from the previous years also. A patient might cancel surgery due to long wait times and she might choose a private clinic, other health authority, or other country where wait times are shorter.

Fig. 5.2 shows the rate of surgeries performed by each surgeon per year.

Figure 5.2: Percentage of Surgeries Performed by Each Surgeon in Northern Health (2008-2012 July)

Here we have used pseudo names for surgeons. It shows that the number of surgeries performed by each surgeon varies significantly. On average, Dr. C and Dr. D performed more than 30% and 36% of the total surgeries respectively, whereas, others percentages are less than or equal to 20%, specially, Dr. A and Dr. E performed almost 2.5 times less number of operations in comparison to them. Some surgeons are very busy, because they receive more referred patients, as a result, their wait lists are longer than other surgeons who have less patients. Fig. 5.3 shows the percentage of patients that each surgeon received in each year at UHNBC.

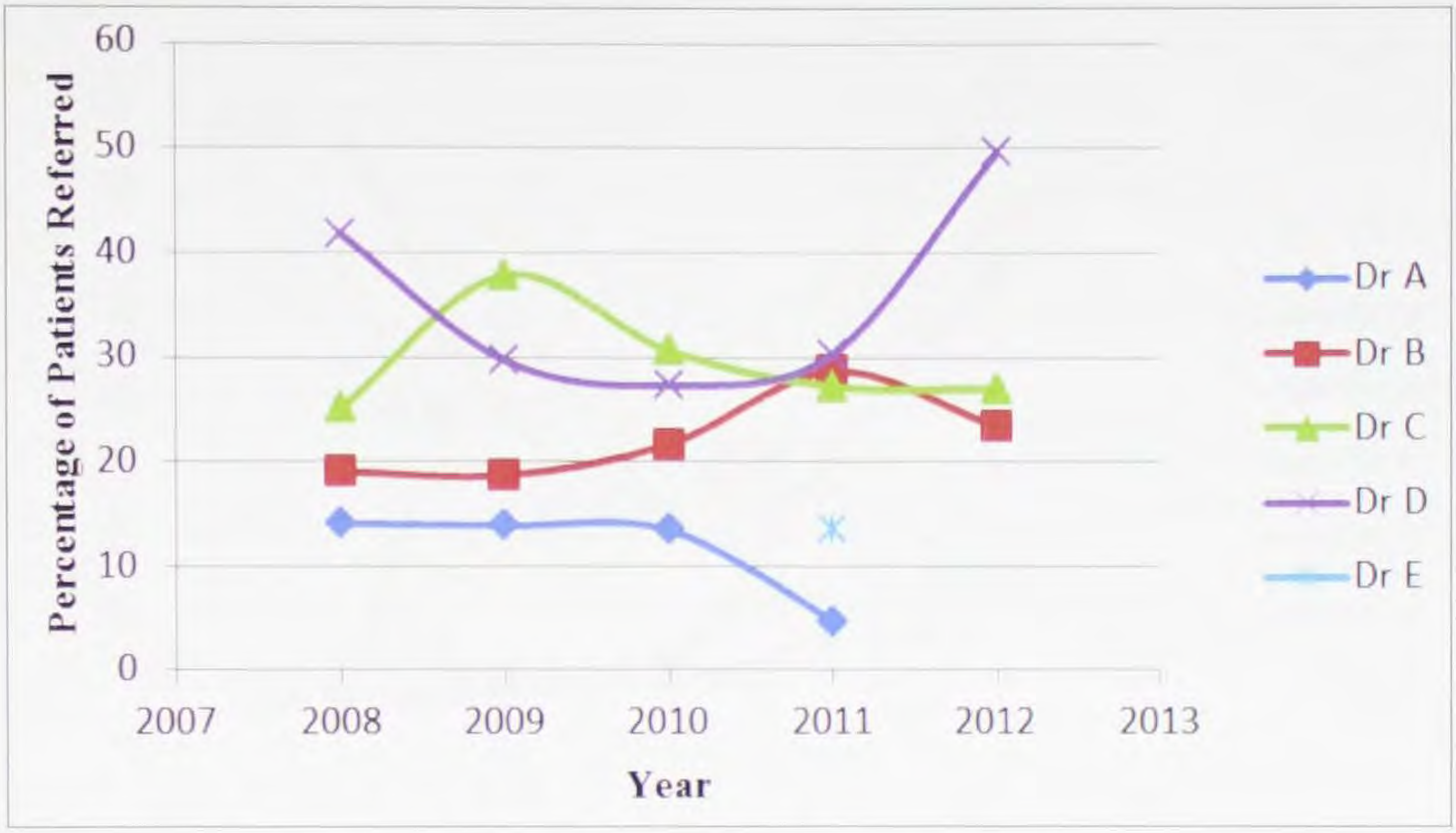

Figure 5.3: Percentage of Patients Referred to Each Surgeon in Northern Health (2008-2012 July)

We did not receive any data about wait time 1 as including this information into the system has become mandatory from April 1, 2014. The average wait time 2 of NH from 2008 to 2012 are 14.97, 15.44, 10.77, 12.75, and 18.96 weeks respectively; this does not present the real story though. If we look at both graphs (fig. 5.2 and fig. 5.4), it is seen that the surgeons who have performed more surgeries (that means they have more patients), their individual wait times 2 are much more than the average wait time per year.

Figure 5.4: Average Wait Time 2 of Each Surgeon Per Year in Northern Health (2008-2012 July)

The Simulation experiments and observations are explained in the following sub-sections. The experiments are categorized based on the research questions.

5.1.2 Experiments for How to Reduce Wait Times

Three experiments are done to find the answer of the first scenario of the first research question; how to reduce wait times with current resources? These experiments are done without adding extra resources. The experiments are given below.

5.1.2.1 Experiment 1: Impacts of Patient Referral Methods

Patient referral from GP to surgeon is one important issue for long wait times. Sometimes a patient has to wait more for a surgeon appointment (wait time 1) than for surgery (wait time 2). Historical data of Northern Health shows that two surgeons among five got almost the double number of patients than other three surgeons and their wait times are very long. Among the NH surgeons, some are too busy, doing almost half of the total operations, whereas others are doing 15% or 20% of the rest. This causes a long wait.

For this experiment we have run simulation by changing the patient referral method from GPs to surgeons. This does not require extra resources. We would like to see whether the proposed two alternative methods (uniform distribution of patients to surgeons and send patients to a surgeon with least number of patients) result in reduced wait times than the existing method (set different percentage of patients to different surgeons). We would also like to observe which method makes optimum OR utilization. The first method refers patients to surgeons with the least number of patients, the second method, uniform distribution, sets 20% patients to each of five surgeons, and the last method sets different percentage of patients for five surgeons (5%, 24%, 27%, 30% and 14%, these sample values are taken from historical record of UHNBC, NH, year 2011). Other parameters' values are set as follows: patient arrival rate/day is three, number of OR is one, number of surgeon is five, 250 patients for each backlog, no priority scheduling is used, some patients cancelled the procedure, and some slates are unused by the surgeons.

Observation on Wait Times: Simulation result shows that mean wait time 1 and 2 (fig. 5.5 and fig. 5.6) are least for the first method (refer patients to the surgeon with least patients) as in this method no surgeons will be overloaded, all will have a balance in the number of patients. Uniform distribution has second least mean wait time as it tries to create equal balance in the number of patients of each surgeon. But if some surgeon has way more patients than others, as in the third method, then her wait time will be too long and other surgeons will have idle time, and this creates longer average wait times. Mean wait time 1 does not show significant difference among the three methods as the surgeons spend more days (at least four week days) to visit patients, so most of the patients are done with first meeting with the surgeon within less time.

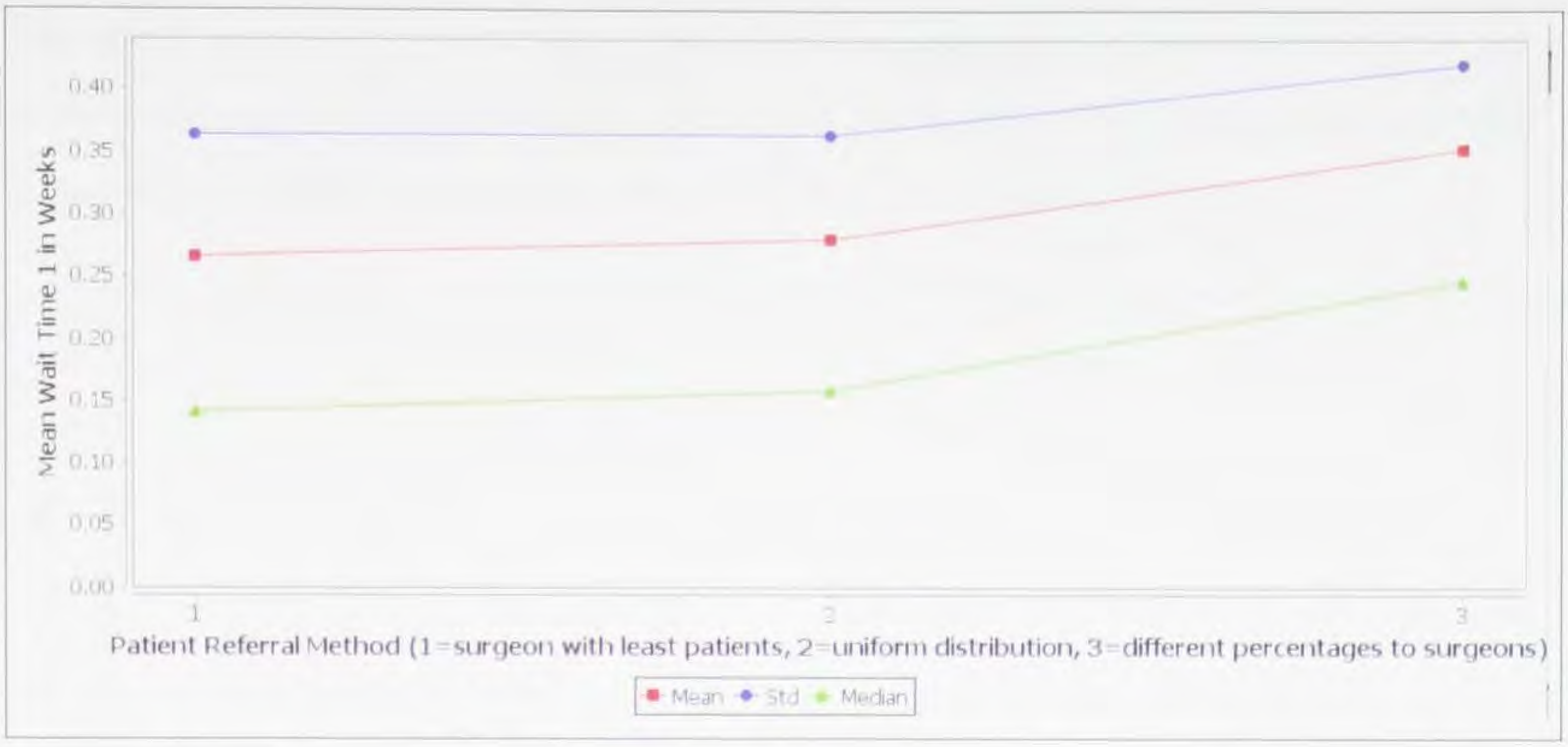

Figure 5.5: Experiment 1: Mean Wait Time 1 (by Varying Patient Referral Methods)

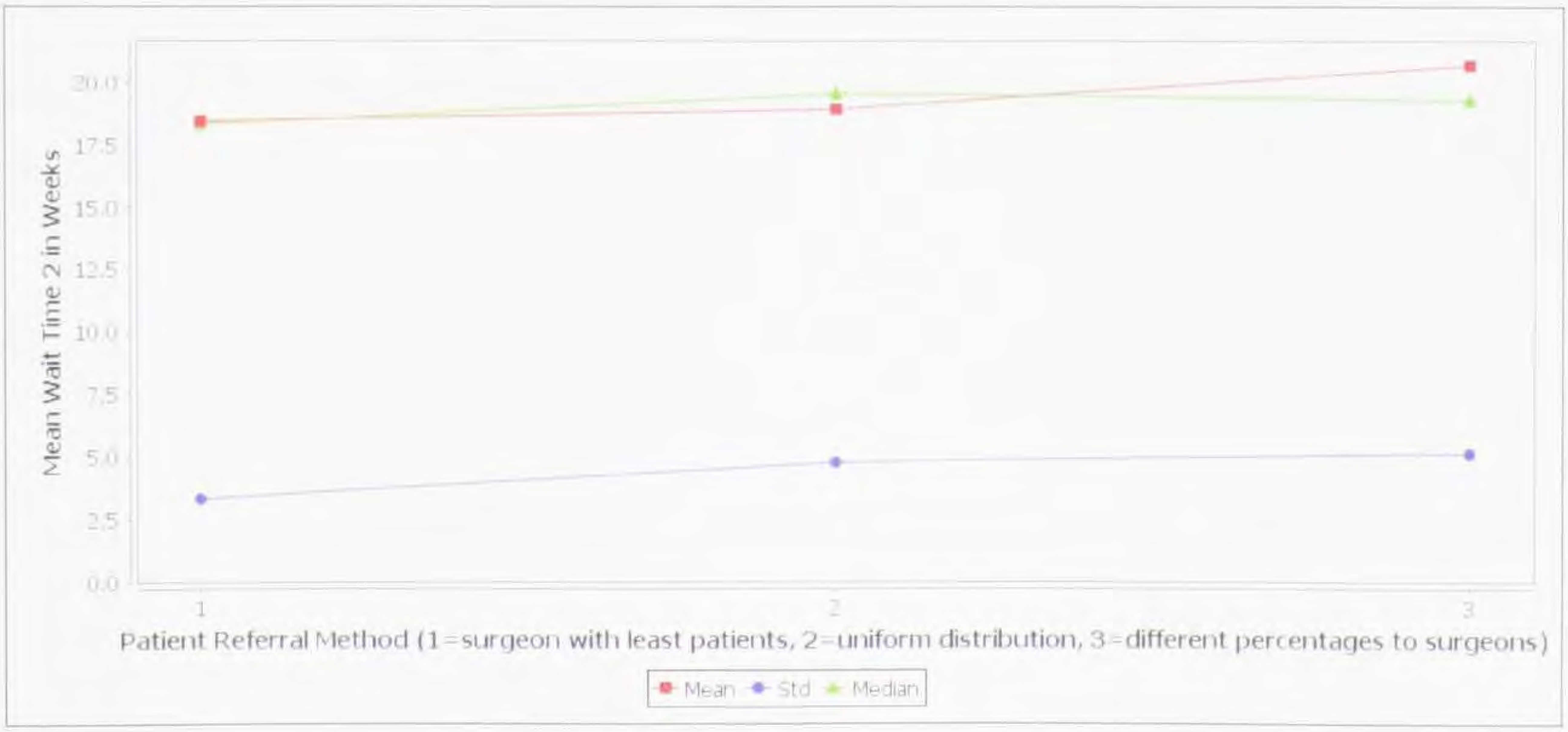

Figure 5.6: Experiment 1: Mean Wait Time 2 (by Varying Patient Referral Methods)

The wait time distribution graphs show the difference among three methods more clearly. The distribution of wait time 1 (fig. 5.7) shows that the third method, different percentages of patients to different surgeons, has slightly longer wait times for patients to meet the surgeons for the first time than in the other two methods.

The graph in fig. 5.8 shows that most of the patients for the first two methods are done with surgery within 20 weeks, whereas, in the third method, different percentage of patients to different surgeons, this wait time is more than 22 weeks.

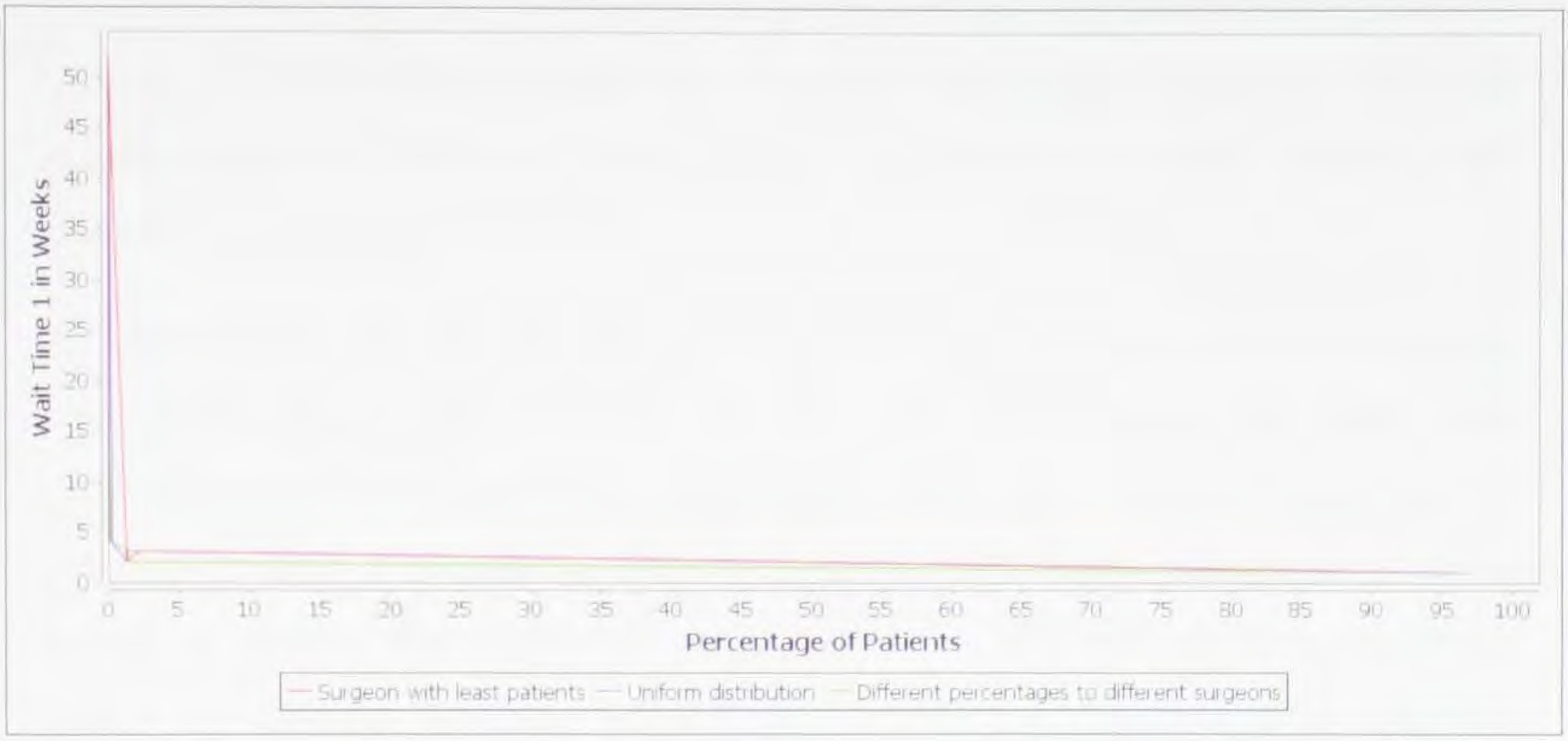

Figure 5.7: Experiment 1: Wait Time 1 Distribution (by Varying Patient Referral Methods)

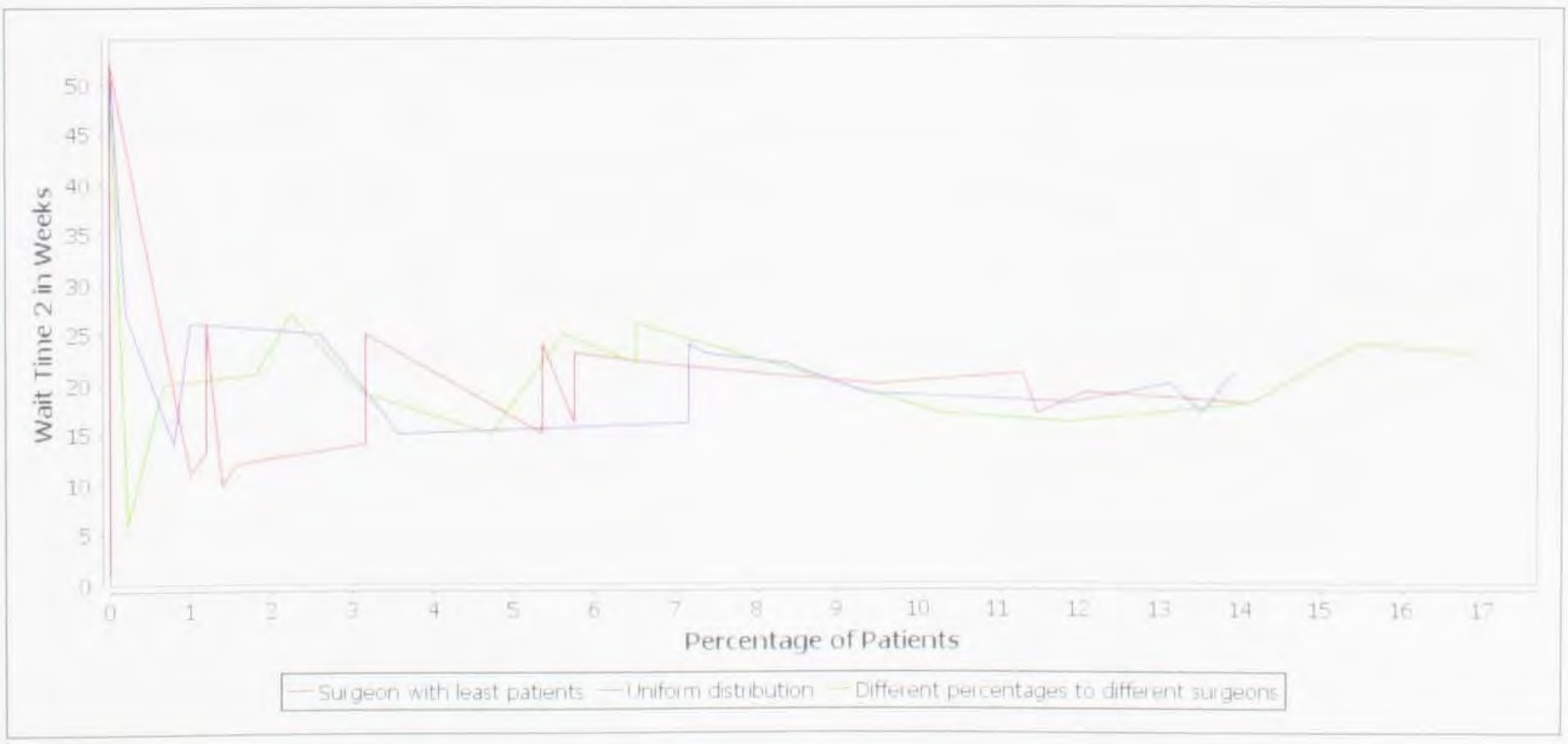

Figure 5.8: Experiment 1: Wait Time 2 Distribution (by Varying Patient Referral Methods)

Our observation shows that, if the GPs don't have information about the surgeons' workload, then they should refer patients to them uniformly. If they have information about each surgeon's workload, then the patients should be referred to the surgeon with the least number of patients. This would eliminate overloading surgeons with patients and would also eliminate the possibility of surgeons having idle time due to lack of patients. Either of these methods will reduce wait times 1 and 2 of the patients.

Observation on Percentage of Surgeries Done: The results of the experiment, in this case as well, show that the first method produces the best result, then uniform distribution of patients to all surgeons takes next place, and assigning different percentages of patients to different surgeons method is in the last place. Total number of patients who underwent surgery are 64%, 62% and 56% respectively for these three methods. We observe that the third method (the present method of NH) shows that the least number of surgeries are done because some surgeons with more patients performed less surgeries in comparison to their huge wait list, and hence the result is less percentage of surgeries done in total. We see that, the more surgeries done indicates the lesser wait times.

Observation on OR Utilization: OR utilization graph (fig. 5.9) shows that the third method, different percentages of patients to different surgeons, made 82% utilization of OR and the first two methods made more than 90% of OR utilization. We observe that the third method makes less use of OR as in most cases the unused slates of the surgeons who had less patients were not used by other surgeons who had more patients.

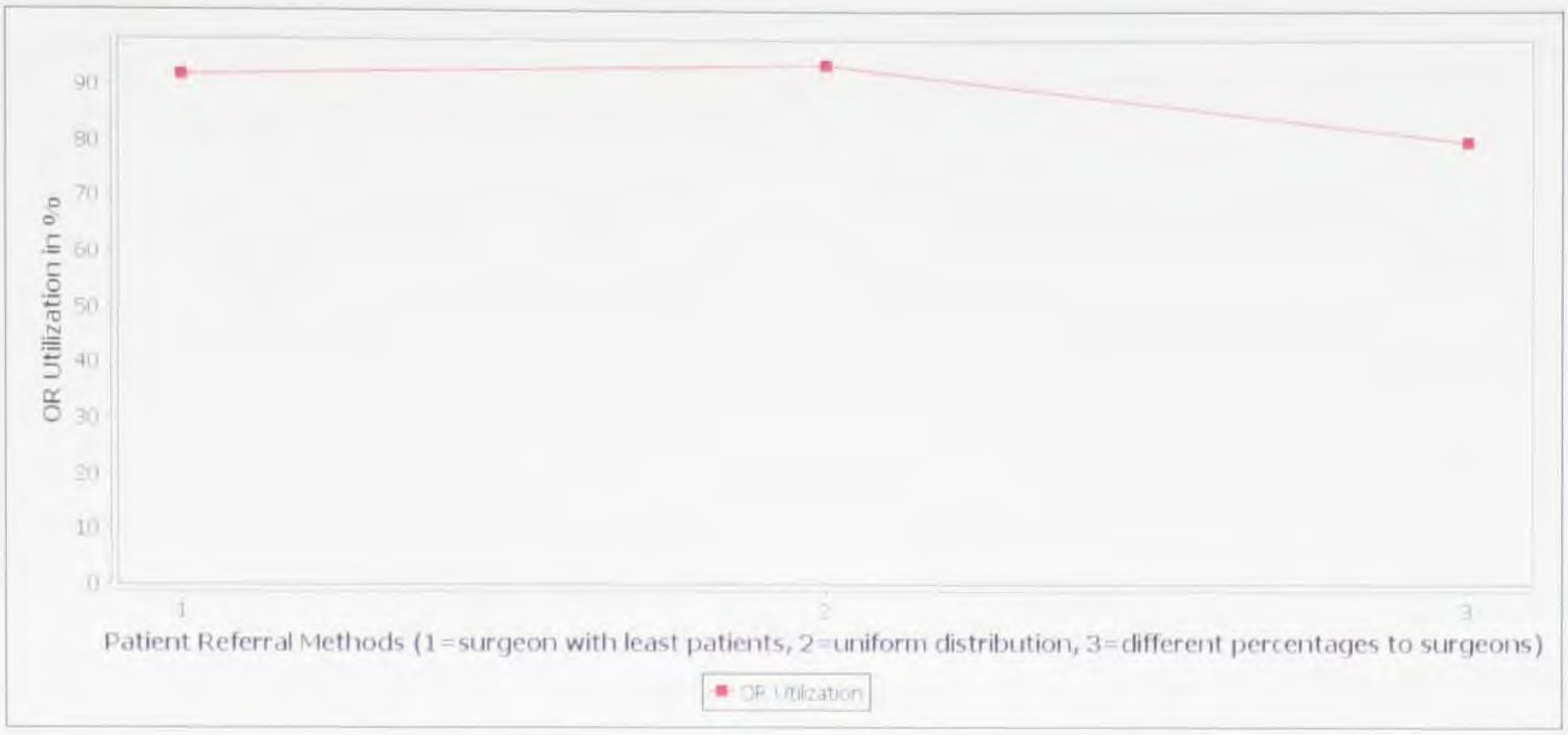

Figure 5.9: Experiment 1: OR Utilization (by Varying Patient Referral Methods)

5.1.2.2 Experiment 2: Impacts of Priority Scheduling

We already know that improper scheduling of patient wait list is one of the main reasons for long wait times and patient dissatisfaction, because, in traditional FCFS scheduling, the patient with major problems has to wait almost as long as a patient waits with minor problems. In this experiment, we have run simulation without and with applying priority scheduling. We implemented the Manitoba Waiting List Program priority system to schedule patients instead of traditional FCFS system to see whether this scheduling improves the wait time 2 of patients. Other simulation parameters' values are set as follows: patient arrival rate/day is three, patient referral method is uniform distribution, number of OR is one, number of surgeon is five, 250 patients for each backlog, some patients cancelled the procedure, and some slates are unused by the surgeons.

Observation On Wait Time 2: The mean wait time 2 is increased by two weeks from 17.61 weeks to 19.22 weeks if the system use priority scheduling as shown in fig. 5.10. This is because the patients with lower priority had to wait more, patients with higher priority received surgeries earlier though.

Figure 5.10: Experiment 2: Mean Wait Time 2 (Using ECFS and Priority Scheduling)

Observation On Percentage of Surgeries Done: The simulation experiment does not show much difference in the performance. The rate of surgery is improved by just 1% from 64% to 65%. Here we observe that, total number of surgeries remains almost the same in both of the cases, as only the patients with more urgency moved forward in the wait list for surgery.

Priority scheduling does not show significant improvement in wait time 2. Using priority scheduling is still fair because: (i) this creates less possibility of injuries due to fall of the patients with major problems; and (ii) more patient satisfaction.

5.1.2.3 Experiment 3: Impacts of Unused Slates of Surgeons

The literature and the information received from NH show that surgeons go on vacation or attend conferences with short notice, and due to miscommunication their operation slates remain unused, which causes long patient wait times and less OR utilization. We have done experiment to see if the use of all slates helps to improve the surgical procedure performance. Other parameters' values are set as follows: patient arrival rate/day is three, patient referral method is uniform distribution, number of OR is one, number of surgeons is five, 250 patients for each backlog, no priority scheduling is used, and some patients cancelled the procedure. The number of unused slates is set as the value of an internal parameter.

Observation on Mean Wait Time 2: We observe that mean wait time 2 gets reduced by almost 4 weeks when all slates are used (fig. 5.11).

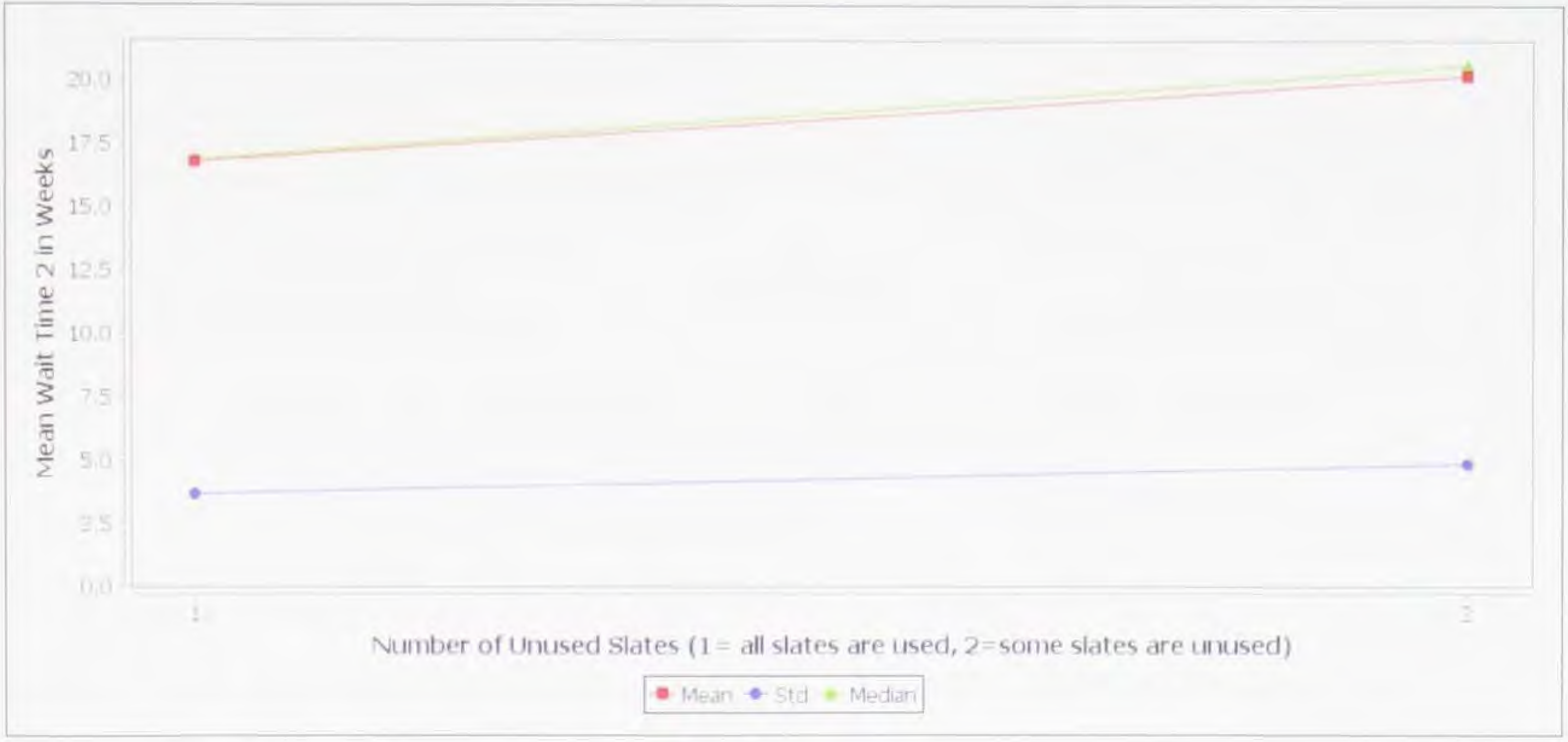

Figure 5.11: Experiment 2: Mean Wait Time 2 (All Slates are Used and Some Slates are Unused)

Observation on Percentage of Surgeries Done: It is seen that if no slates remain unused, the total number of surgery is increased by 5%, from 64% to 69%. The increase of percentage is based on the number of unused slates of each surgeon. For this experiment the number of unused slates of each surgeon is shown in fig. 5.12.

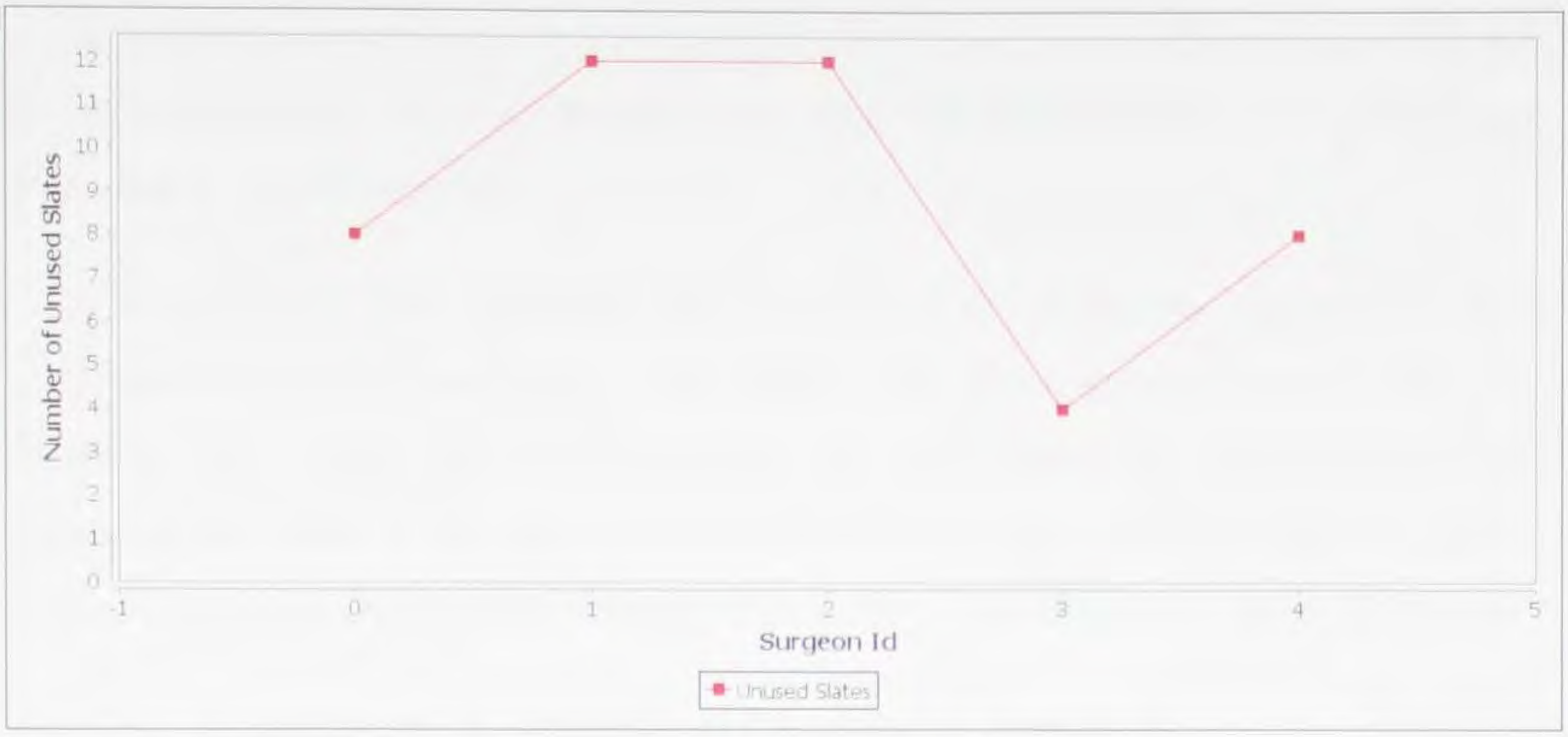

Figure 5.12: Experiment 3: Unused Slates of Each Surgeon

Observation on OR Utilization: If all the slates of each surgeon are used for surgery then the OR will be utilized 100%. The OR utilization graph (fig. 5.13) shows that, when some slates are unused, the OR utilization reduced to 92%, where it shows 100 percent usage with all slates are used.

Figure 5.13: Experiment 3: OR Utilization (All Slates are Used and Some Slates are Unused)

If surgeons inform earlier before going on vacation or to a conference, the OR can be assigned to other surgeons for that time. This will ensure optimum use of OR and wait time 2 will be reduced.

It is easily said that increased number of resources will increase the performance of the present surgical procedure. That means wait times will be reduced and more surgeries will be performed with optimum OR utilization. The second sets of experiments are done to see this rate of improvement; how much the NHCS model's performance is improved with extra resources. Two experiments are described below.

5.1.2.4 Experiment 4: Impacts of Number of Surgeons

A surgeon is one of the most essential parts of any surgical procedure. For this experiment, we have considered three scenarios: (i) what is the performance of the surgical procedure with current resources, that means five surgeons; (ii) what if more surgeons (six to ten) are added to the system; and (iii) what happens if a surgeon gets retired (four surgeons) which indicates less surgeons. We have included the third scenario to show the rate of decrease in performance if the surgical procedure loses a surgeon for some reason. The simulation parameters' values for this experiment are set as follows: patient arrival rate/day is three, patient referral method is uniform distribution, number of OR is one, 250 patients for each backlog, no priority scheduling is used, some patients cancelled the procedure, and some slates are unused by the surgeons.

Observation On Wait Times: Mean wait times 1 and 2 are shown in fig. 5.14 and fig. 5.15.

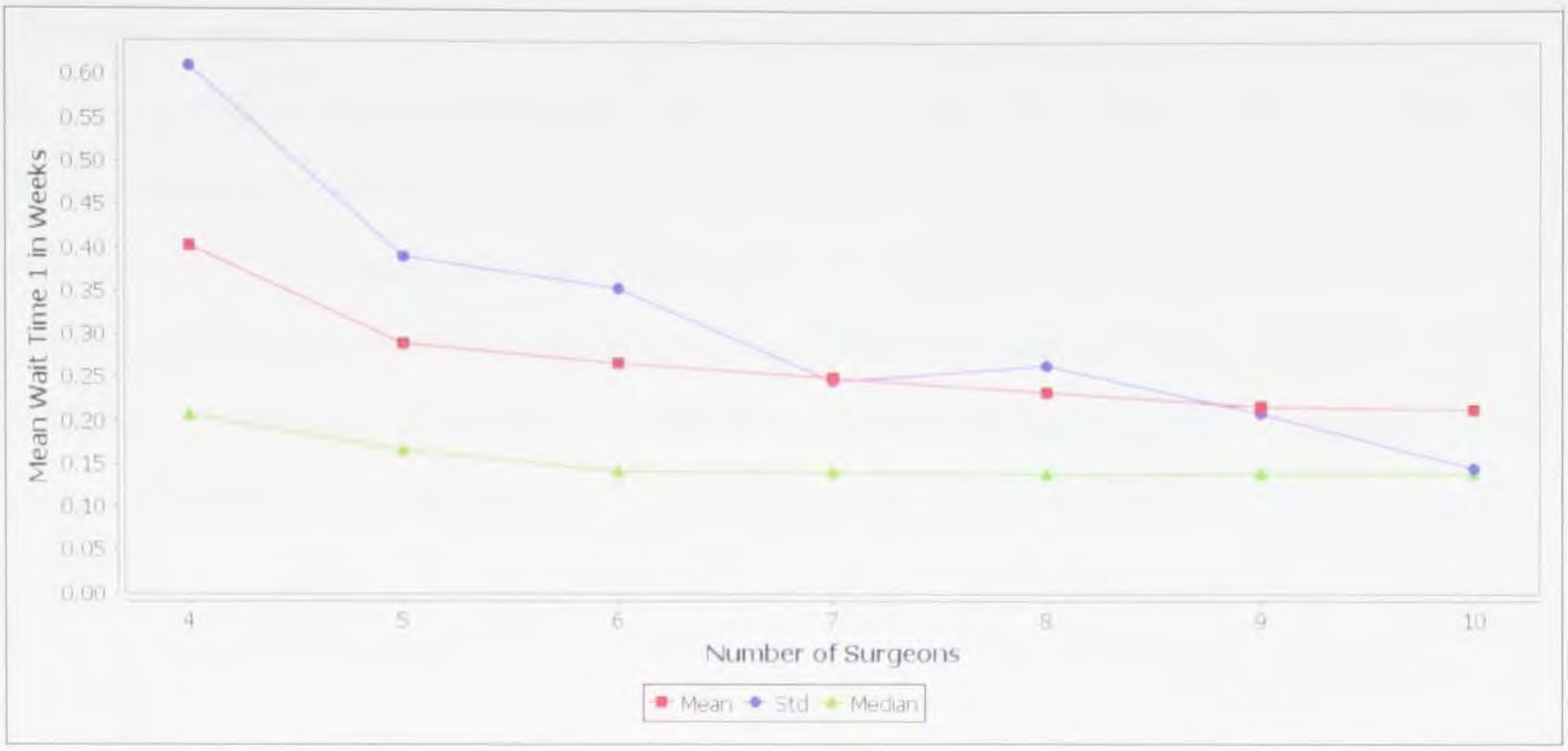

Figure 5.14: Experiment 4: Mean Wait Time 1 (by Varying the Number of Surgeons)

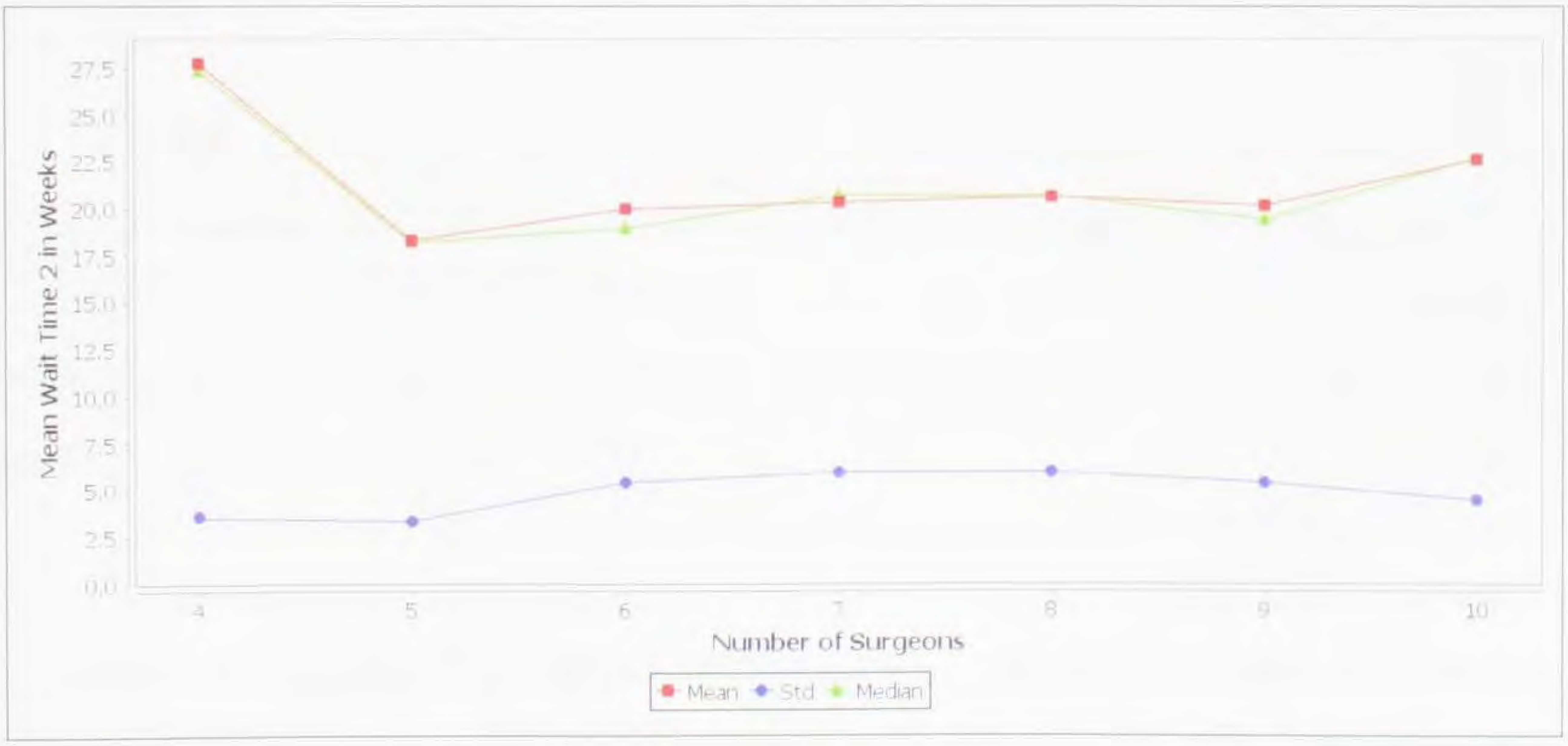

Figure 5.15: Experiment 4: Mean Wait Time 2 (by Varying the Number of Surgeons)

It is observed from fig. 5.14 that mean wait time 1 decreases with the increase in number of surgeons. This is natural, because the more surgeons the system will have, the more the patients will be distributed uniformly to more surgeons. In this way, they will get first appointment within short amount of time. Mean wait time 2 shows the opposite result. The wait time 2 increases with the increase in the number of surgeons (six to ten surgeons). The reason is that, the more surgeons there are in the surgical procedure, the more they have to wait to get their turn to utilize the allocated OR. The only one OR is allocated to surgeons in a round robin fashion. If one surgeon gets retired (four surgeons), the mean wait time 2 will increase by almost 9 weeks (18 weeks to 27 weeks) compared to mean wait time 2 of five surgeons. Wait time 2 distribution graph (fig. 5.16) also supports this statistics.

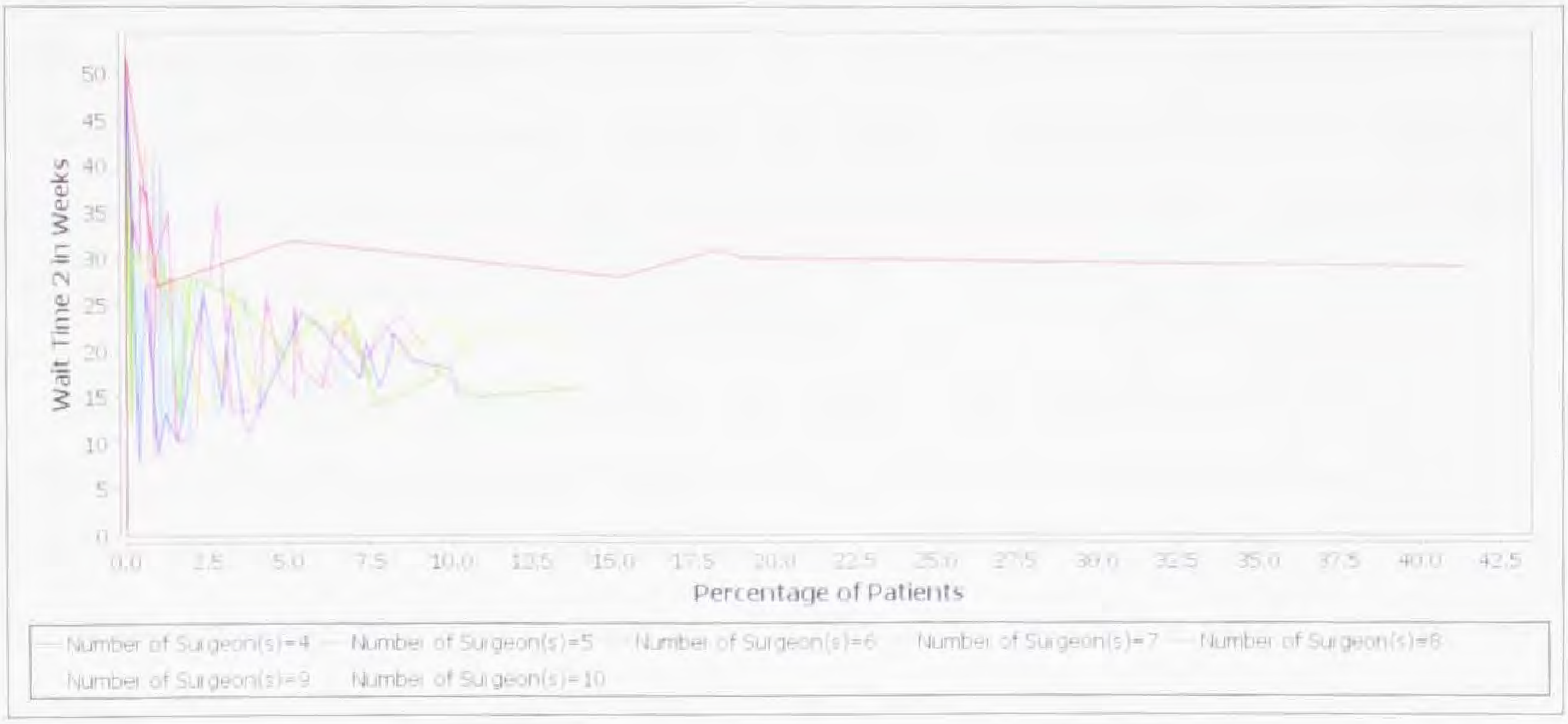

Figure 5.16: Experiment 4: Wait Time 2 Distribution (by Varying Number of Surgeons)

Observation On Percentage of Surgeries Done: Simulation experiment shows that NHCS model performs 68% surgery with five surgeons. The rate of surgery decreases with adding more surgeons (6 to 10 surgeons), the decrease rate is between 63% to 66%. This is because of the same reason of using round robin fashion to allocate the OR to surgeons. If a surgeon gets retired, the percentage is reduced to 52%, which is 16% less surgery than in the present situation.

From this experiment we observe that, Northern Health should have five surgeons. As there are five week days, and each day the OR is assigned to only one surgeon for surgery in a round robin fashion, five surgeons would make proper use of the OR and reduce wait time.

5.1.2.5 Experiment 5: Impacts of Number of ORs

Having sufficient number of ORs and optimum use of existing ORs are very important to reduce patient wait times for surgery and do more surgeries. We have run simulation for one year by increasing the number of ORs starting from one to three with five surgeons (right now NH has five surgeons) to compare the results. Other simulation parameters' values are set as follows: patient arrival rate/day is three, patient referral method is uniform distribution, 250 patients for each backlog, no priority scheduling is used, some patients cancelled the procedure, and some slates are unused by the surgeons.

Observation On Wait Time 2: The graph in fig. 5.17 shows that mean wait time gets reduced more than half from 19.67% to 8.93%, if we add one more OR only. The use of three ORs results in almost the same mean wait time as for two ORs. This is because a surgeon is able to use only one OR at a time on her scheduled day. So if two ORs can be kept ready for her, she will be able to use the ORs alternatively which will not add inter operation preparation time and the surgeon will be able to perform atleast one more surgery in the fixed time period for surgery. In the present surgical procedure, having more than two ORs is not useful as the surgeon will perform surgery in one OR, the second will be kept ready for the next operation, and other(s) will remain unused always.

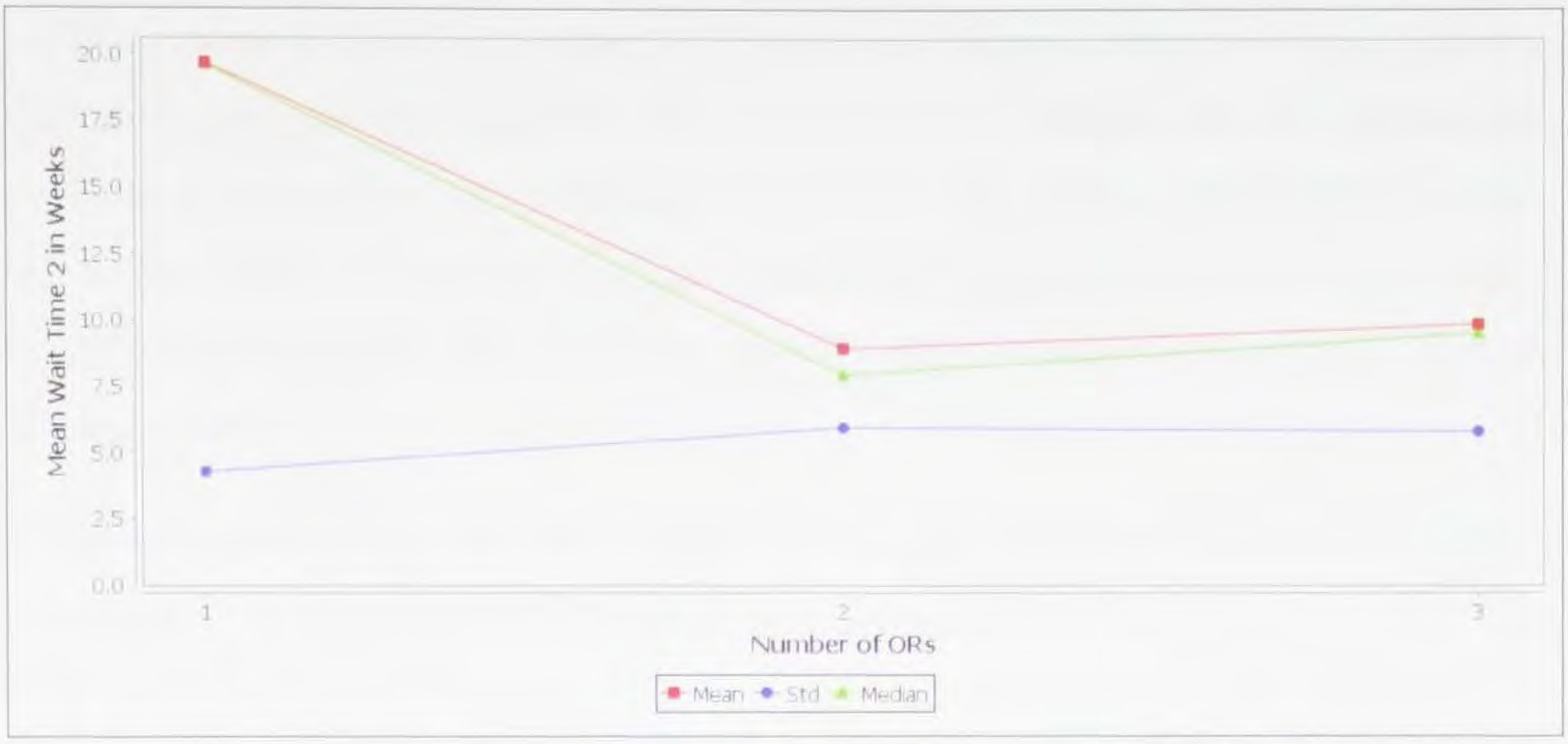

Figure 5.17: Experiment 5: Meant Wait Time 2 (by Varying the Number of ORs)

The wait time 2 distribution graph in fig. 5.18 shows that most of the patients get their surgery done within a maximum of 15 weeks for two and three ORs, whereas, with one OR, their wait time is maximum 25 weeks. That means adding just one more OR will improve the reduction of wait time 2 significantly.

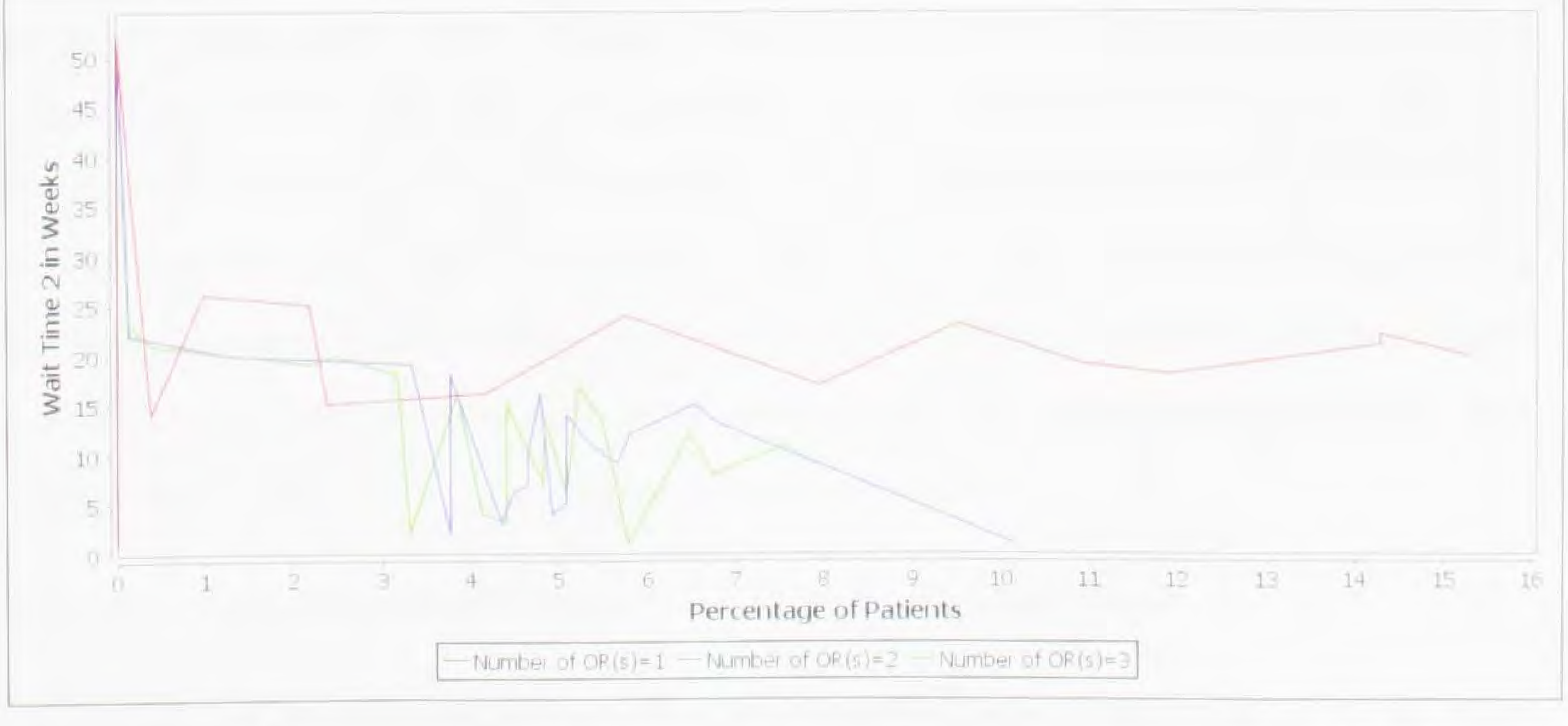

Figure 5.18: Experiment 5: Wait time 2 Distribution (by Varying the Number of ORs)

Observation On Percentage of Surgeries Done: Simulation result shows that if we increase the number of OR by one, from one to two, the rate of surgery performed increases by 25%, from 63% to 88%. The use of three ORs does not show any improvement in the rate of surgery performed (the percentage of surgery done is 88%), because the surgeon used the two ORs alternatively and the third OR was unused always.

So we would like to say that, assigning maximum two ORs for cataract surgery would be the optimum use of ORs at present situation.

5.1.3 Experiments to Show the Impacts of Patient Population

The number of patients in the wait list is an important factor that increases or decreases wait times. More patients result in longer wait times. The backlog patients added to the current patient list also increase wait times and decrease the rate of total surgeries. Here we have done three experiments to get the answer of this research question: What is the impact of the patient list size (both current and backlog patients) on wait times and total surgery done? In the first experiment, the patient arrival rate is increased based on the population demography to get an idea about the patient list size in coming future years and percentage of possible surgeries done. This experiment will answer another research question: If NH does not increase resource or change scheduling, what will be the performance of the surgical procedure in the future? The second experiment is done to see the negative impact of having backlog patients on the system performance. The third experiment shows if some patients cancel the surgical procedure due to long wait or some other reasons, how that helps to improve the wait times of other patients.

5.1.3.1 Experiment 6: Impacts of Patient Arrival Rate

We know that most of the eye cataract patients (more than 70%) are 65 or older. Population demography says that NH is going to have almost the double number of the senior citizens from 2011 to 2025. The data we have collected from UHNBC hospital shows that the patient arrival rate per day is approximately 2.5 for each year (2008 to 2012). This arrival rate is going to be double according to the age demographic change. We would like to see the impact of increased arrival rate of patients on the system with present procedure and resource: what is the probable total incoming patients in future years, how many patients will be done, and what would be the wait times?

For this experiment, we have varied the patient arrival rate from three to ten per day based on the information given above. Other simulation parameters' values are fixed such as patient referral method is uniform distribution, number of OR is one, number of surgeons is five, zero patient for each backlog, no priority scheduling is used, some patients cancelled the procedure, and some slates are unused by surgeons.

Observation on Probable Incoming Patient List Size: The variation in arrival rates gives information about the possible number of incoming patients for future years. Fig. 5.19 presents this information based on arrival rate per year. We observe that if the arrival rate keeps increasing like this in future years, NH has to face huge number of patients in coming years and their wait times will be longer if they don't add more resources.

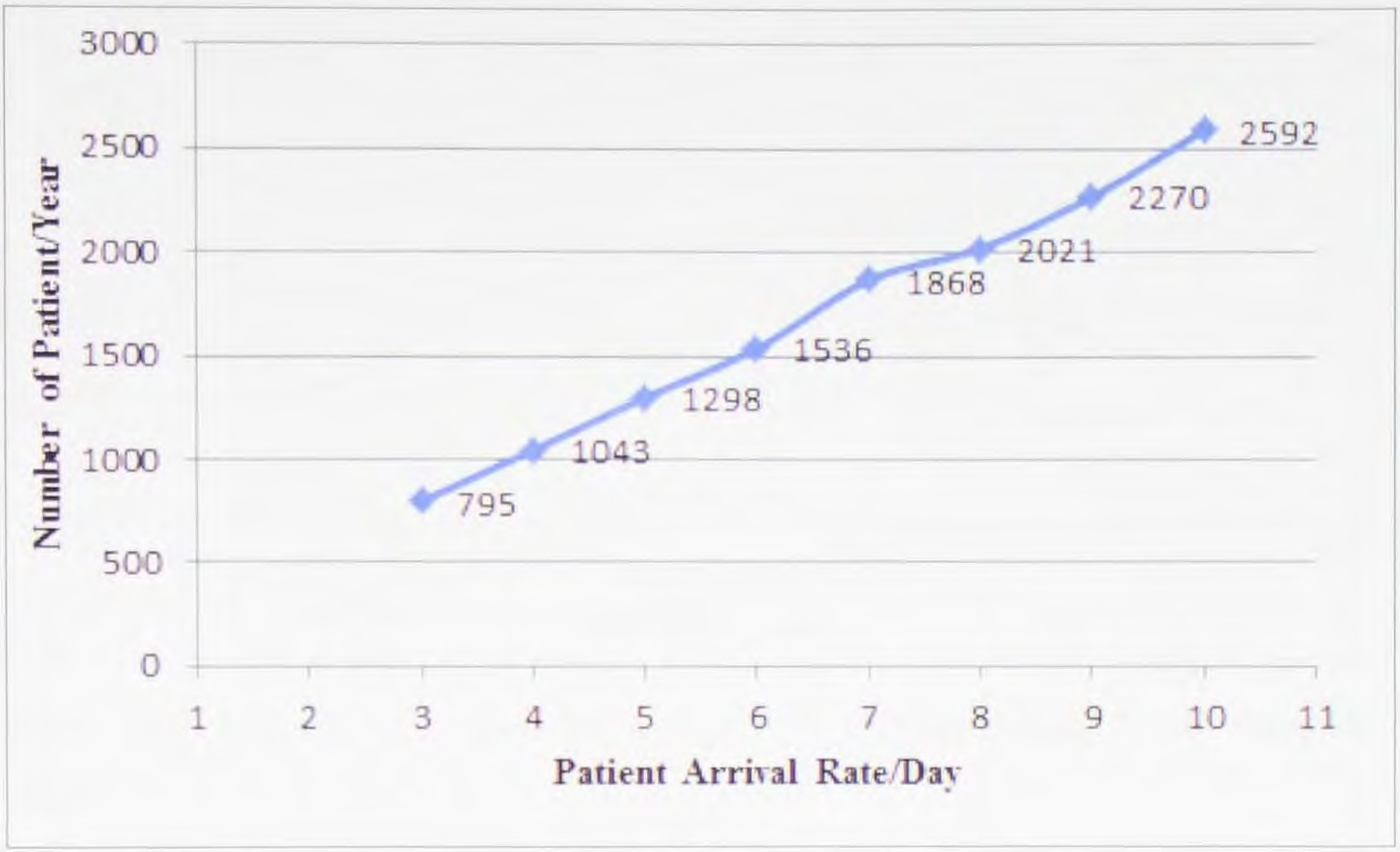

Figure 5.19: Experiment 6: Future Incoming Patients (by Varying Patient Arrival Rate Per Day)

Observation on Wait Times: Mean wait time 1 is shown in fig. 5.20. The graph shows that mean wait time 1 increases steadily, the rate of increase is slow though. This is because a number of patients arrive every week day based on arrival rate and each surgeon meets patients every week day except for one day she performs surgery.

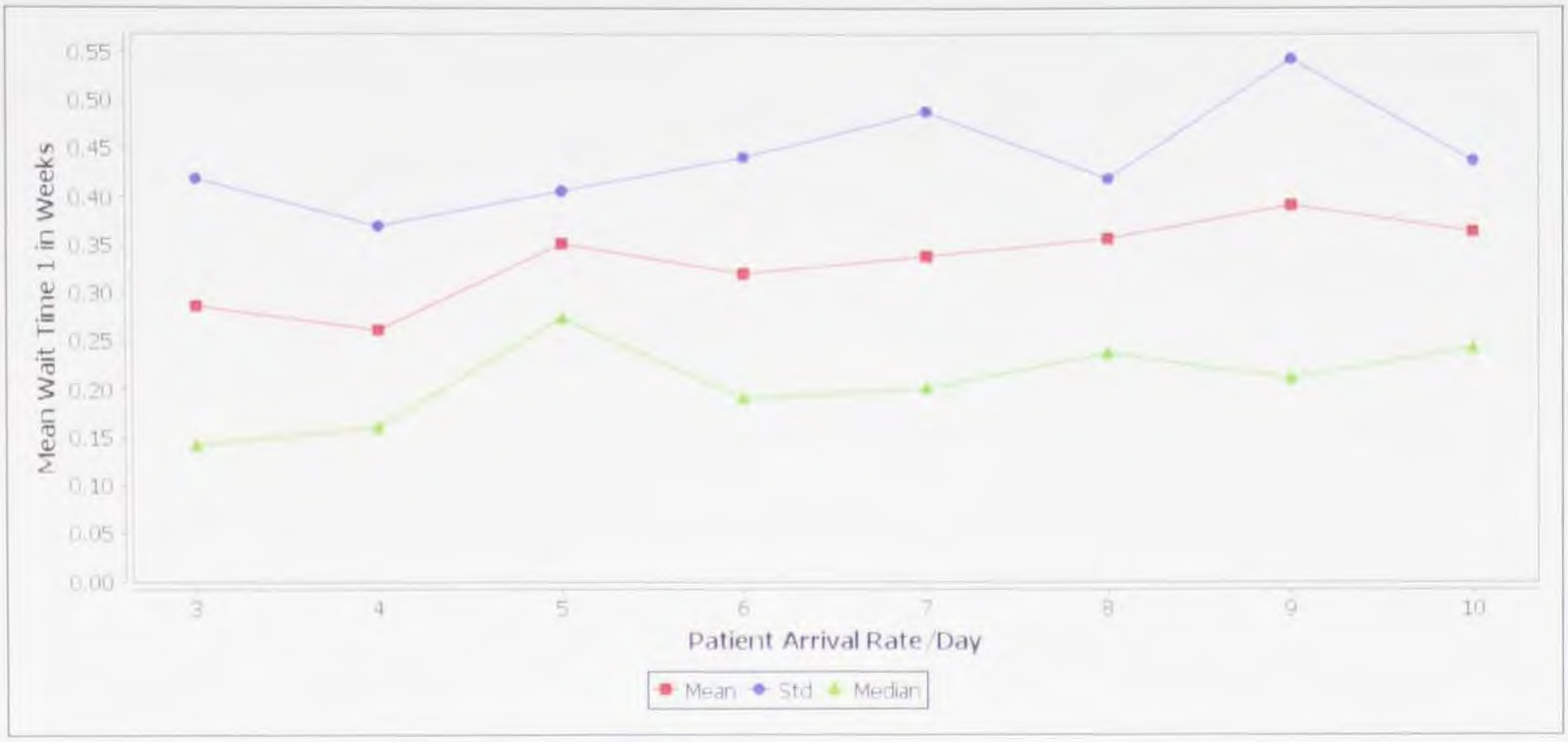

Figure 5.20: Experiment 6: Mean Wait Time 1 (by Varying Patient Arrival Rate Per Day)

Mean wait time 2 shows a big difference between arrival rates three and ten (fig. 5.21). Mean wait time 2 is almost double when arrival rate reached ten per day from the arrival rate three per day. Mean wait time 2 exceeds the target wait time, 16 weeks, for all arrival rates. This is very alarming as we know from the population demography that every coming year NH will have more and more patients.

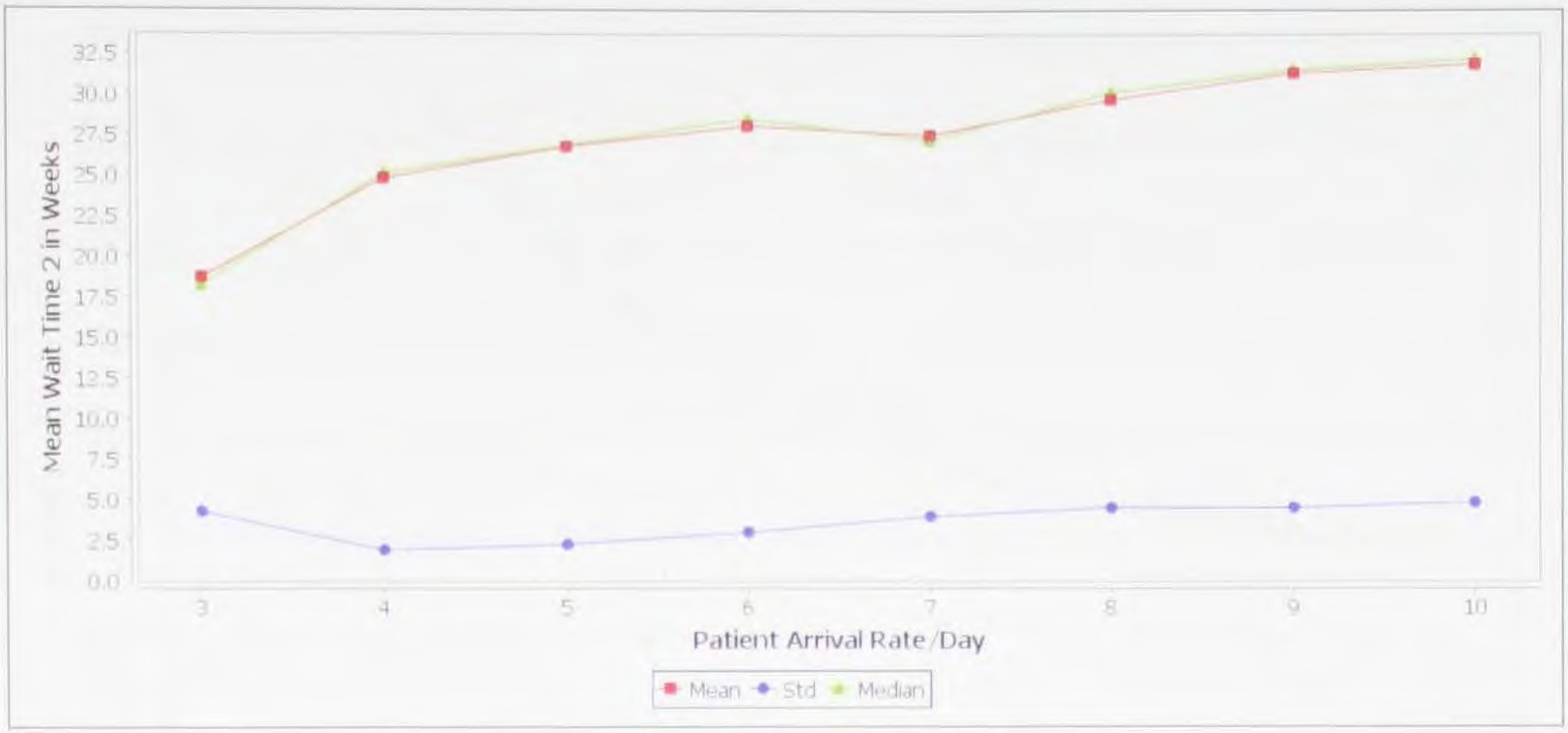

Figure 5.21: Experiment 6: Mean Wait Time 2 (by Varying Patient Arrival Rate Per Day)

We observe that increasing of patient arrival rate/day does not create much pressure on wait time 1 in comparison to wait time 2 as surgeons visit patients more days (four week days) than they perform surgeries.

Observation on Percentage of Surgeries Done: Percentage of surgeries done for this experiment is shown in fig. 5.22.

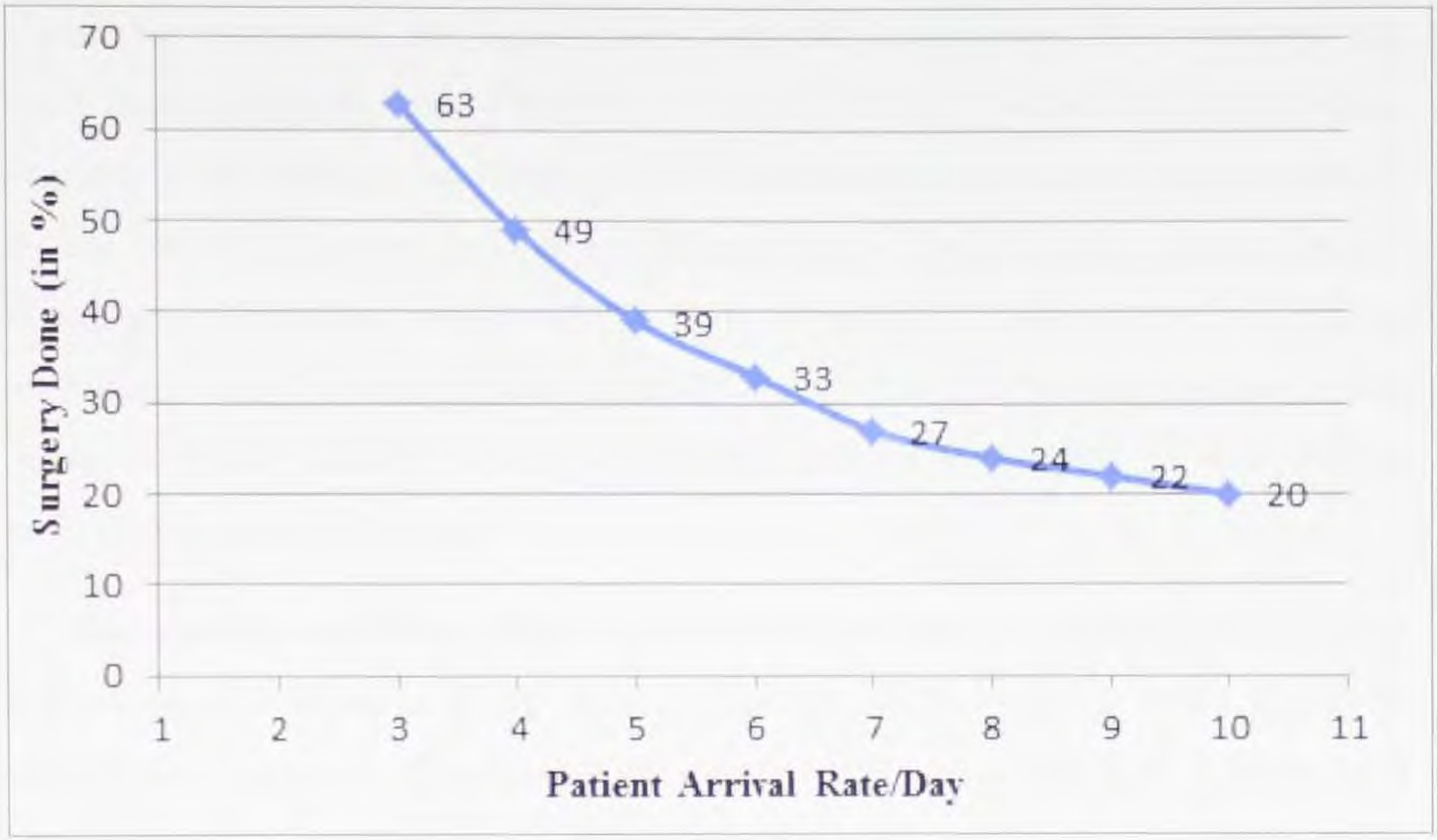

Figure 5.22: Experiment 6: Percentage of Surgeries Done (by Varying Patient Arrival Rate Per Day)

Here we observe that if patient arrival rate per day increases atleast by one in each year, the number of surgery will be decreased significantly, by almost 40% in the next 10 years, if NH continues their surgical procedure with present system and resources. Because, in that case, every surgeon will receive much more referred patients for surgery, and they will not be able to do more surgery with present resource (one OR) and scheduling policy (one day only for surgery for every surgeon).

5.1.3.2 Experiment 7: Impacts of Backlog Patients

Patients already waiting either to meet a surgeon or for surgery from previous year is a major cause of excessive wait times. The NH has an approximate average of 250 backlog 2 patients every year. In this experiment, we would like to observe how much the wait times get reduced and overall surgery rate is improved if there is no backlog patients.

In this experiment, we have set zero and 250 patients for both backlogs. We don't have information about backlog 1 patients. So we have set the same amount of patients for backlog 1 as backlog 2 for this simulation set up. Other parameters' values are set as follows: patient arrival rate/day is three, patient referral method is uniform distribution, number of OR is one, number of surgeon is five, no priority scheduling is used, some patients cancelled the procedure, and some slates are unused by the surgeons. We have shown here the impact of having backlogs on total number of surgeries and wait times.

Observation on Wait Times: The mean wait time 1 decreases slightly from 0.34 weeks to 0.23 weeks if 250 backlog 1 patients is decreased to zero. Fig. 5.23 shows this information. Mean wait time 1 does not show big difference between zero and 250 backlog 1 patients as again for the same reason, each surgeon meets patients everyday except for one day when she performs surgery.

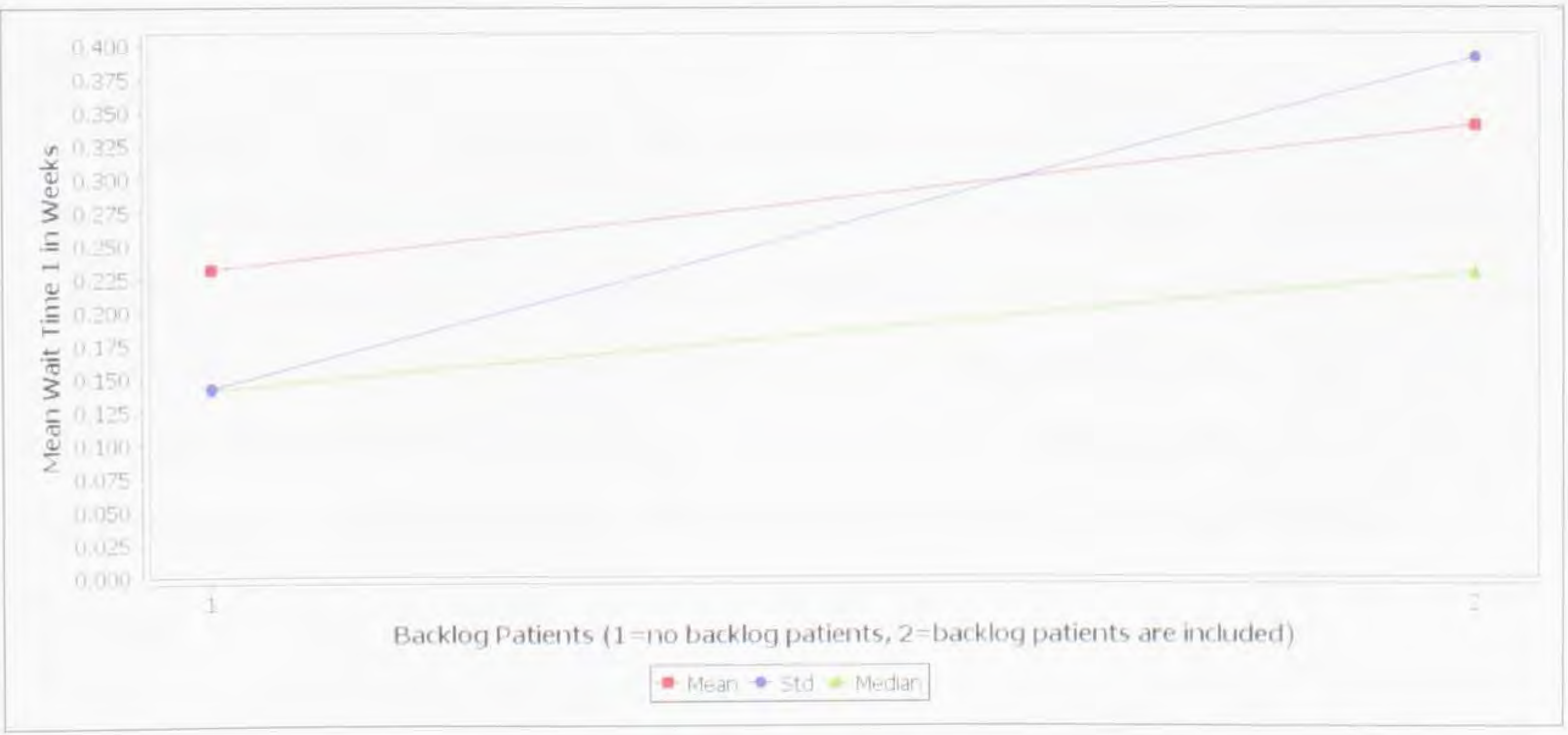

Figure 5.23: Experiment 7: Mean Wait Time 1 of Patients (with Backlog 0 and 250)

The distribution graph (fig. 5.24) of wait time 1 presents that slight improvement. It is seen in the graph that 100% patients got first appointment with their surgeons within one week when backlog 1 patient is zero, whereas the wait time is more than a week for 5% patients only if there are 250 backlog 1 patients.

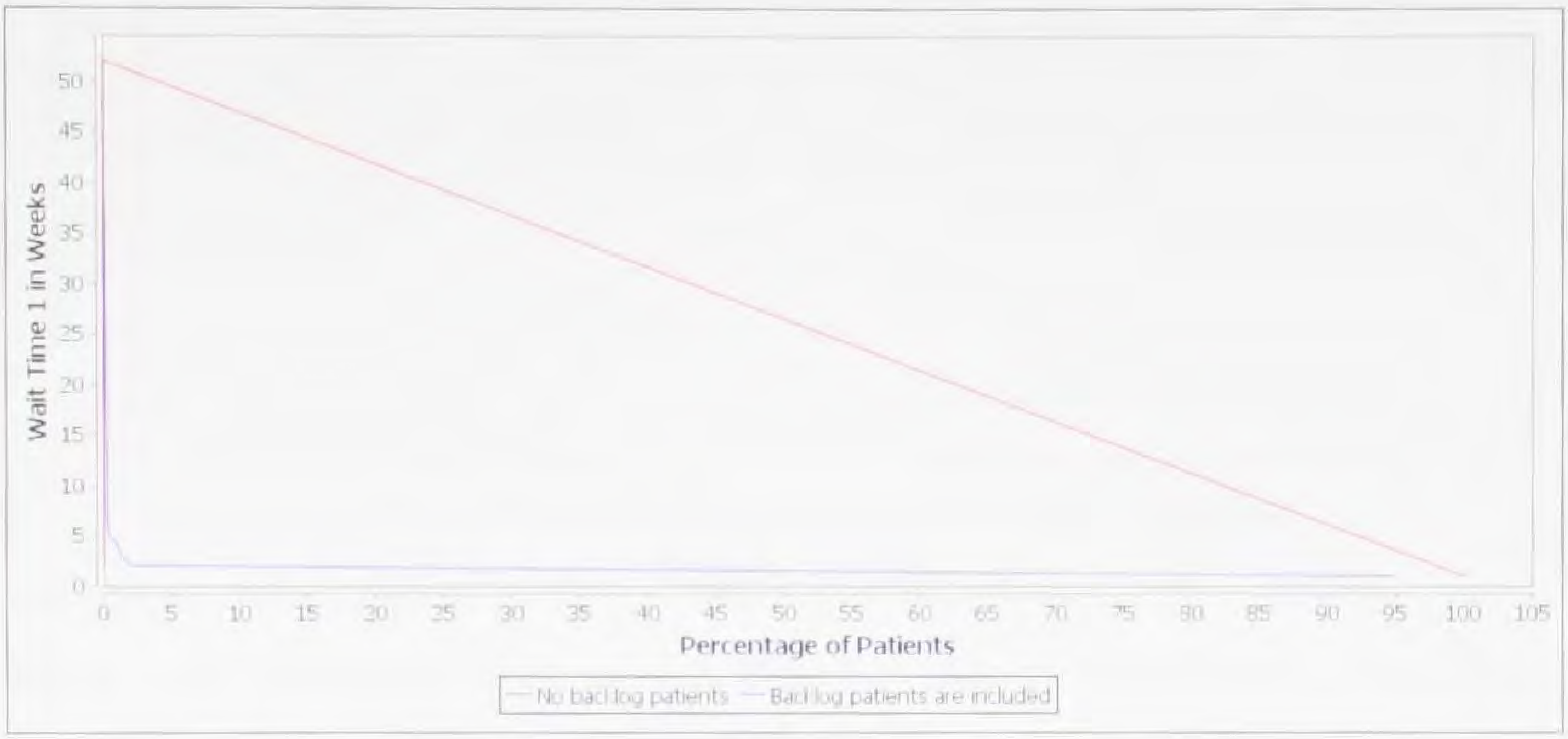

Figure 5.24: Experiment 7: Wait Time 1 Distribution of Patients (with Backlog 0 and 250)

The graph in fig. 5.25 shows huge difference in mean wait time 2 if the system does not have backlog patients. Mean wait time 2 is more than 21 weeks which is almost 20 times more than the mean wait 2 (2 weeks) without any backlog. Because in this case, surgeons first operate the backlog 2 patients, then the backlog 1 patients, and finally the patients who are entered in the system for this current year. This huge long wait times result in patients being dissatisfied by the service provided.

Figure 5.25: Experiment 7: Mean Wait Time 2 of Patients (with Backlog 0 and 250)

The distribution of this wait time is shown in fig. 5.26. Minimum wait time 2 is 16 weeks with backlog patients whereas maximum wait time 2 is less than 5 weeks if the system does not have any backlog.

Figure 5.26: Experiment 7: Wait Time 2 Distribution of Patients (with Backlog 0 and 250)

Observation on Percentage of Surgeries Done: The simulation result for this experiment shows that total number of surgeries performed will be improved significantly if NH does not have any backlog patients. The percentage of surgery done is 92 without any backlog, which is almost double compared to having backlog patients that is 58%.

Our observation shows that if NH does not have any backlog patients, their mean wait time 2 will be much less than the target wait time 2, and this will result in greater patient satisfaction.

5.1.3.3 Experiment 8: Impacts of Cancellation of the Surgical Procedure by Patients

Sometimes the patients cancel first meeting with surgeon and surgery due to long wait and choose other country, other health authority, or private clinic to complete the eye cataract surgical procedure. It is important to keep record of the number of patients that voluntarily withdraw themselves from the procedure, because this reduces wait times of other patients.

We have done experiment to see the difference in behaviour of surgical procedure if no patients cancel surgical procedure and some patients (this value is set in terms of percentage as an internal parameter) cancel their procedure. Other parameters' values are set as follows: patient arrival rate/day is three, patient referral method is uniform distribution, number of OR is one, number of surgeon is five, 250 patients for each backlog, no priority scheduling is used, and some slates (this value is set in terms of percentage as an internal parameter) are unused by the surgeons. For this experiment, 6% patient cancelled the procedure during each wait time (wait time 1 and wait time 2).

Observation on Wait Times: We observe in the mean wait time 1 graph (fig. 5.27) that mean wait time 1 is decreased slightly from 0.29 weeks to 0.26 weeks, because if a few patients cancel their first meeting with surgeons, that does not affect the wait time 1 much, as surgeons visit patients all other days except for the surgery day. On the other hand, mean wait time 2 shows better improvement, from 21.60 weeks to 18.13 weeks (fig. 5.28) if some patients cancel their scheduled surgery.

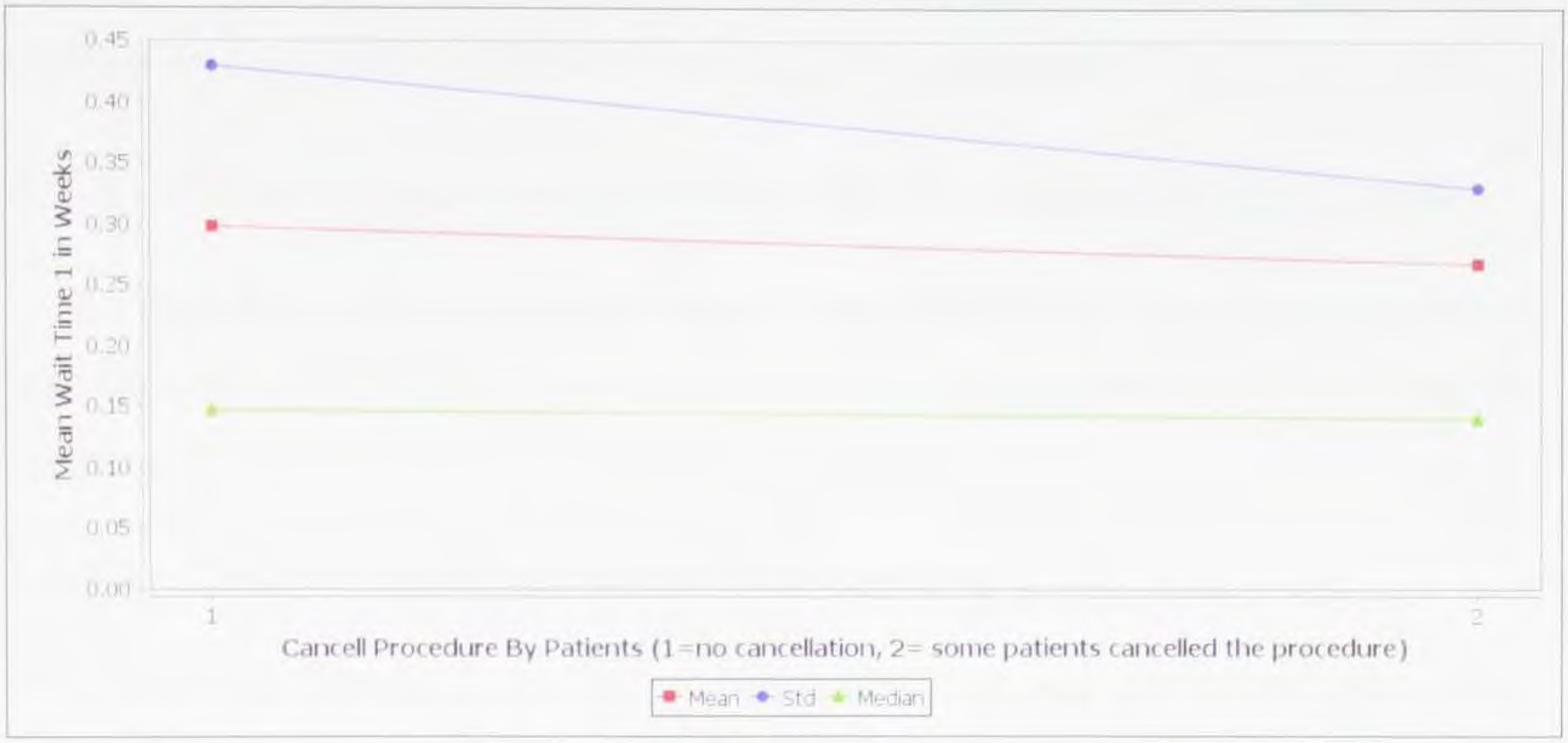

Figure 5.27: Experiment 8: Mean Wait Time 1 without and with Patients Cancelled the Procedure

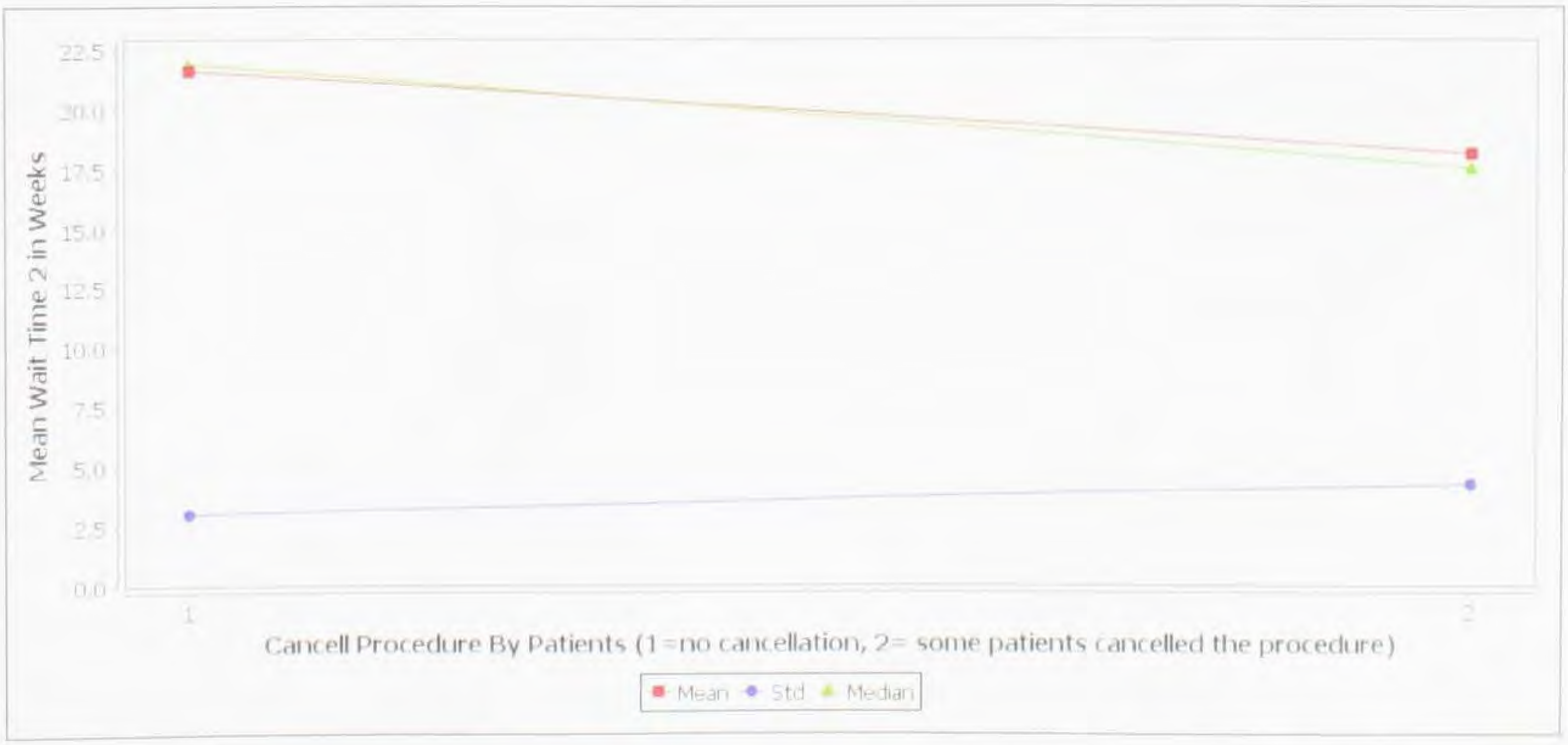

Figure 5.28: Experiment 8: Mean Wait Time 2 without and with Patients Cancelled the Procedure

Observation on Percentage of Surgeries Done: The percentage of surgery performed is 63% when no patients cancelled the procedure, and the percentage is 66% when 69 patients (8.98% of the total number of patients arrived) cancelled the surgical procedure either at wait times 1 or 2. The improvement in percentage basically depends on the number of patients who cancel the procedure.

5.1.4 Simulation Comparison with Northern Health Data

We have done a simulation experiment to see how accurate the proposed simulator is to reproduce the NH historical data. This experiment answers the fourth research question.

5.1.4.1 Experiment 9: Simulation Comparison

For this experiment, we have run simulation for each year (2008-2012) that represents historical data of those year. Simulation parameters with their values used for this experiment are given in table 5.3. We have used the percentages of patients that are referred to each surgeon from Fig. 5.3.

Parameter	Value
Patient Arrival Rate	3
Patient Distribution to Surgeon	different percentages to different surgeons
Number of OR	1
Number of Surgeon	4, 4, 4, 5, 3
Backlog1	250
Backlog2	232, 255, 256, 329, 303
Priority Scheduling	no
Procedure Cancelled by Patients	yes
Unused Slates by Surgeons	yes
Run Simulation for	365 days

Table 5.3: Simulation Parameters and Their Values Used for Simulation Comparison

Observation on the Total Number of Patients Arrived: Total number of patients arrived in this experiment and actual number of patients arrived in each year are shown in fig. 5.29.

Figure 5.29: Experiment 9: Total Number of Actual and Simulated Patients Arrived in Each Year

From this graph we observe that, the actual number of patients arrived in each year is greater than the number of patients arrived in the simulation experiment. Poisson distribution was used to generate patients in each year based on the number of patients arrive per day. The graph shows almost double patients in the simulation than the total number of actual patients arrived in 2012, this is because, we received data till July for that year.

Observation on the Percentage of Total Surgery Done: The percentage of surgeries done in the simulation experiment and the actual percentage of surgery for each year are given in fig. 5.30.

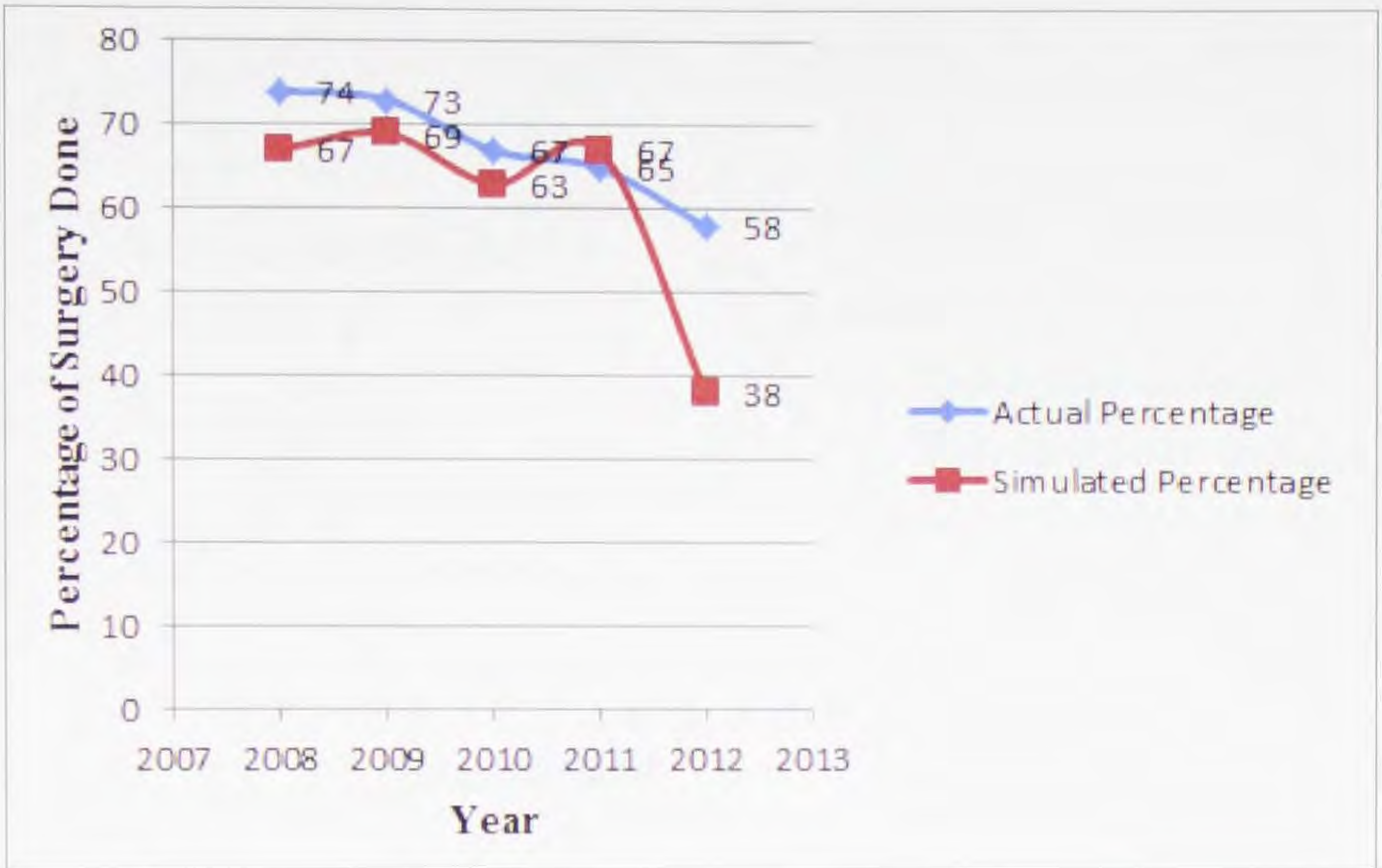

Figure 5.30: Experiment 9: Percentage of Total Actual and Total Simulated Surgeries Done in Each Year

It is seen from this graph that the simulated results are very close to the actual data. Simulated results did not show the actual result, because, the total number of patients who arrived in each year in the simulation was less than the actual data.

Percentage of Surgeries Performed by Each Surgeon: Here we would like to compare the percentage of surgeries performed by each surgeon. We choose to compare simulated results with actual data of 2011, because in this year NH had five surgeons. The total number of patients arrived in the simulation for 2011 is 825. The simulated and actual percentages are given in fig. 5.31.

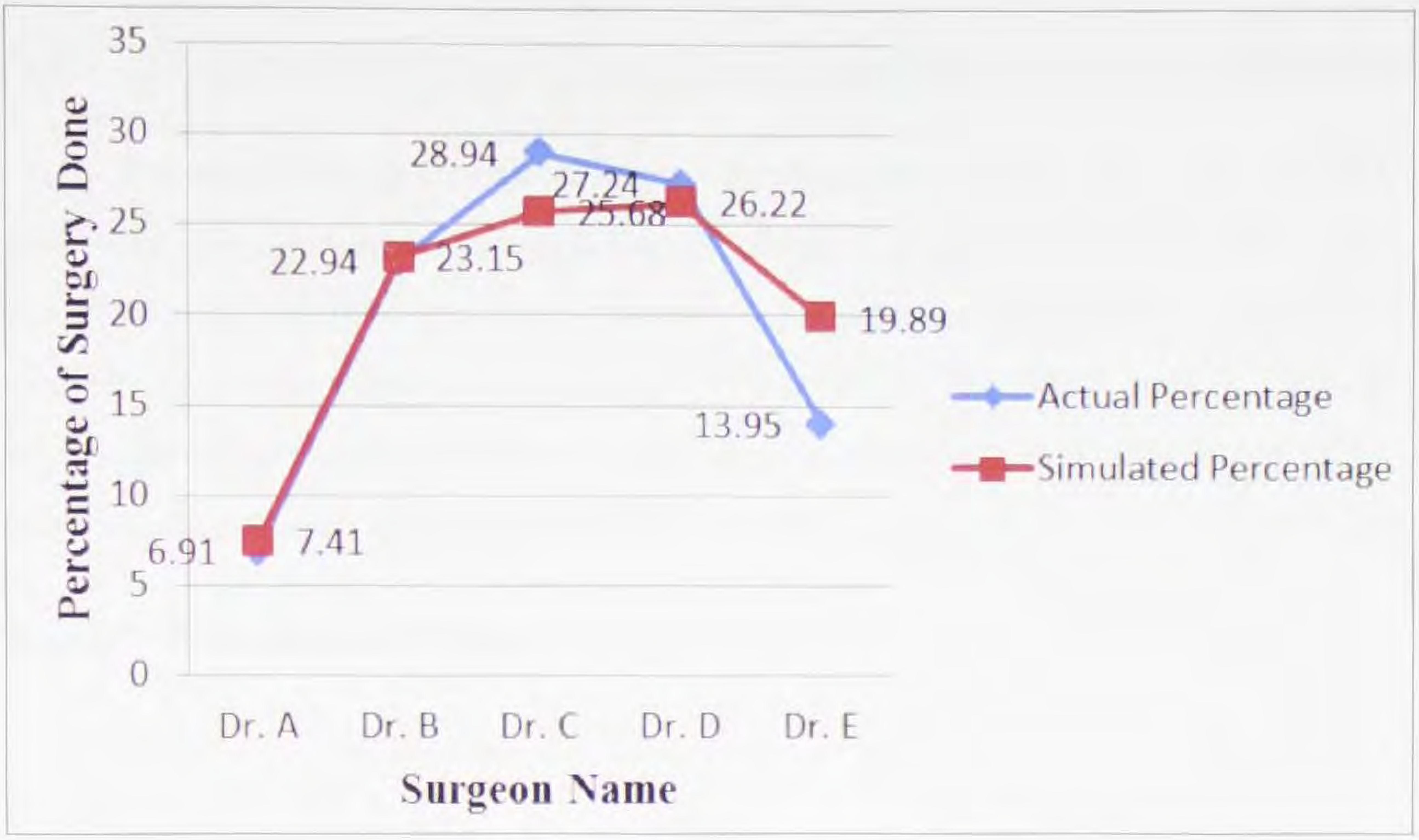

Figure 5.31: Experiment 9: Percentage of Actual and Simulated Surgeries Performed by Each Surgeon in 2011

We observe from this graph that the simulated percentages of surgeries of each surgeon and the actual percentages are very close for 2008, 2009, and 2011 (difference is less than 1%). Again, for 2012, the difference is bigger as the actual percentage is the outcome of seven months (up to July) for that year.

Our observations for this experiment show that the simulated results appear to be visually close to the actual data. The simulated results did not show the exact match as we were not able to set actual number of patients who cancelled the procedure, and actual number of unused slates for each surgeon, because we don't have that information. After comparing the simulated data to the actual data in this experiment, we would like to say that our simulated system is very close to the actual system of NH.

Experiments for the CSG model are presented in the next section.

5.2 Experiment for Cataract Surgery Generic Model

In this simulation study, we have tried to show the performance of the surgical procedure if the model is more generic. We would like to check whether the model has more than one ORs and more than one surgeons work in parallel on each week day, then the wait times get reduced in comparison to the NHCS model. That is why we have done experiments by varying number of surgeons and ORs only as other experiments are done already for the NHCS model.

5.2.1 Simulation Setup

The common simulation parameters and their values used for these experiments are given in the table below.

Parameter	Value
Patient Arrival Distribution	Poisson
Patient Arrival Rate/Day	3
Patient Distribution to Surgeon	uniform
Number of OR	1-5
number of Surgeon	1-15
Backlog1	250
Backlog2	250
Priority Scheduling	no
Procedure Cancelled by Patients	yes
Unused Slates by Surgeons	yes
Run Simulation for	365 days

Table 5.4: Simulation Parameters and Their Values Used for Cataract Surgery Generic Model

All the internal parameters mentioned in section 5.1.1 are also used in this simulation study. One extra parameter is used for this study; 'Max. no. of surgery days for each surgeon on each week', whose value is 2 days.

5.2.2 Experiment 10: Impacts of Number of Surgeons

For this experiment we have varied the value of number of surgeons (1-15), with fixed number of ORs (two ORs), 250 patients for each backlog, and uniform patient distribution, to see the improvement in surgical procedure.

Observation on Mean Wait Times: The mean wait time 1 is shown in fig. 5.32 and fig. 5.33. In mean wait time 1, the mean wait time with one surgeon shows very long wait times, 21.20 weeks, in this case, all patients were referred to one surgeon only. For two to fifteen surgeons, the mean wait time 1 is much less, gradually decreased starting from 2.46 weeks to less than a week, because in these cases, all patients were gradually referred to more surgeons.

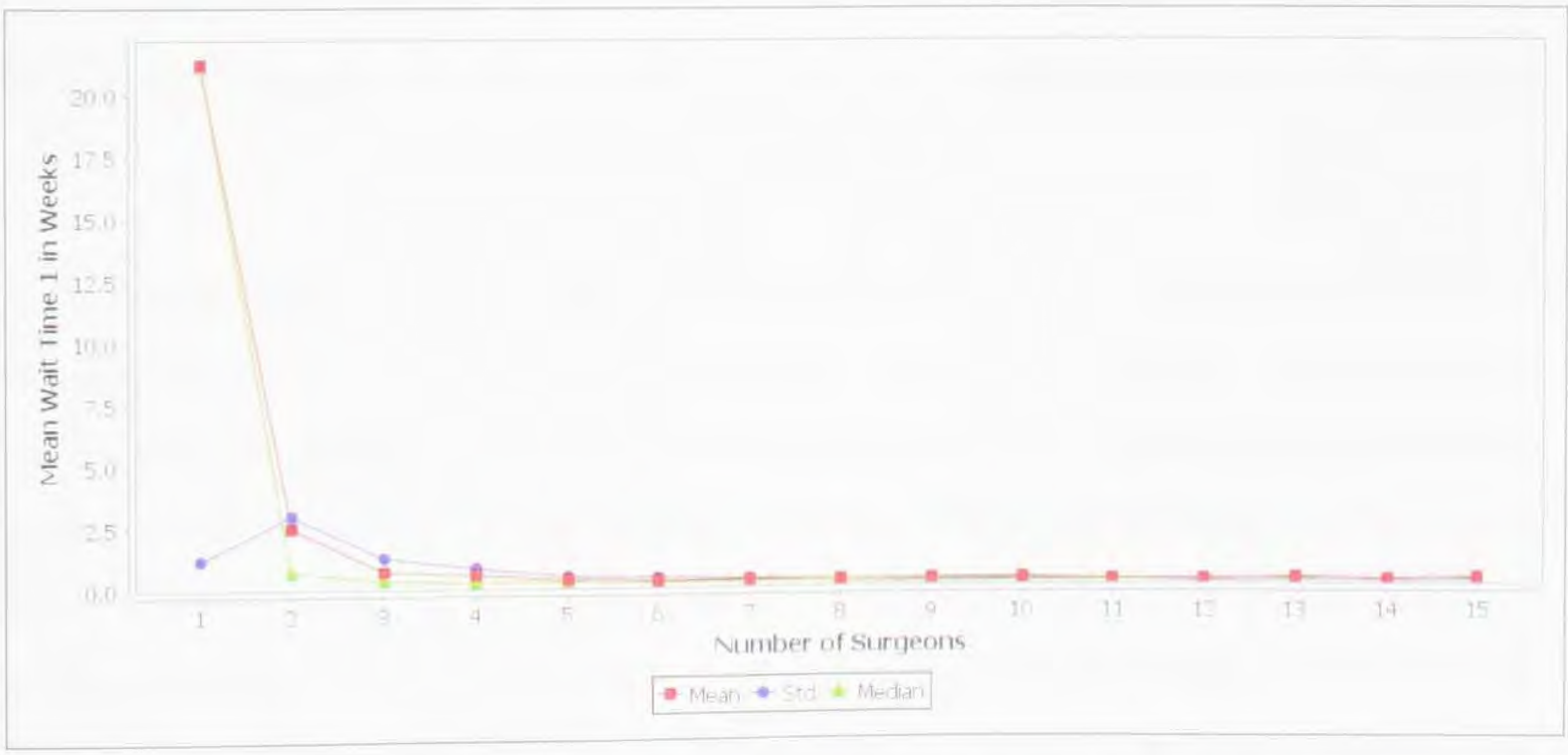

Figure 5.32: Experiment 10: Mean Wait Time 1 (by Varying the Number of Surgeons)

The graph of mean wait time 2 (fig. 5.33) shows that, the wait time is zero for one surgeon, because after completion of surgeries for all backlog patients, the simulation time was over, and the surgeon was not able to start performing surgery for the patients that arrived in the simulation time period. For two to five surgeons, the mean wait time is much less, less than a week, after that the mean wait time increases gradually (from one week to three weeks), as the surgeons number increases, the surgeons have to wait more to get their turn for surgery.

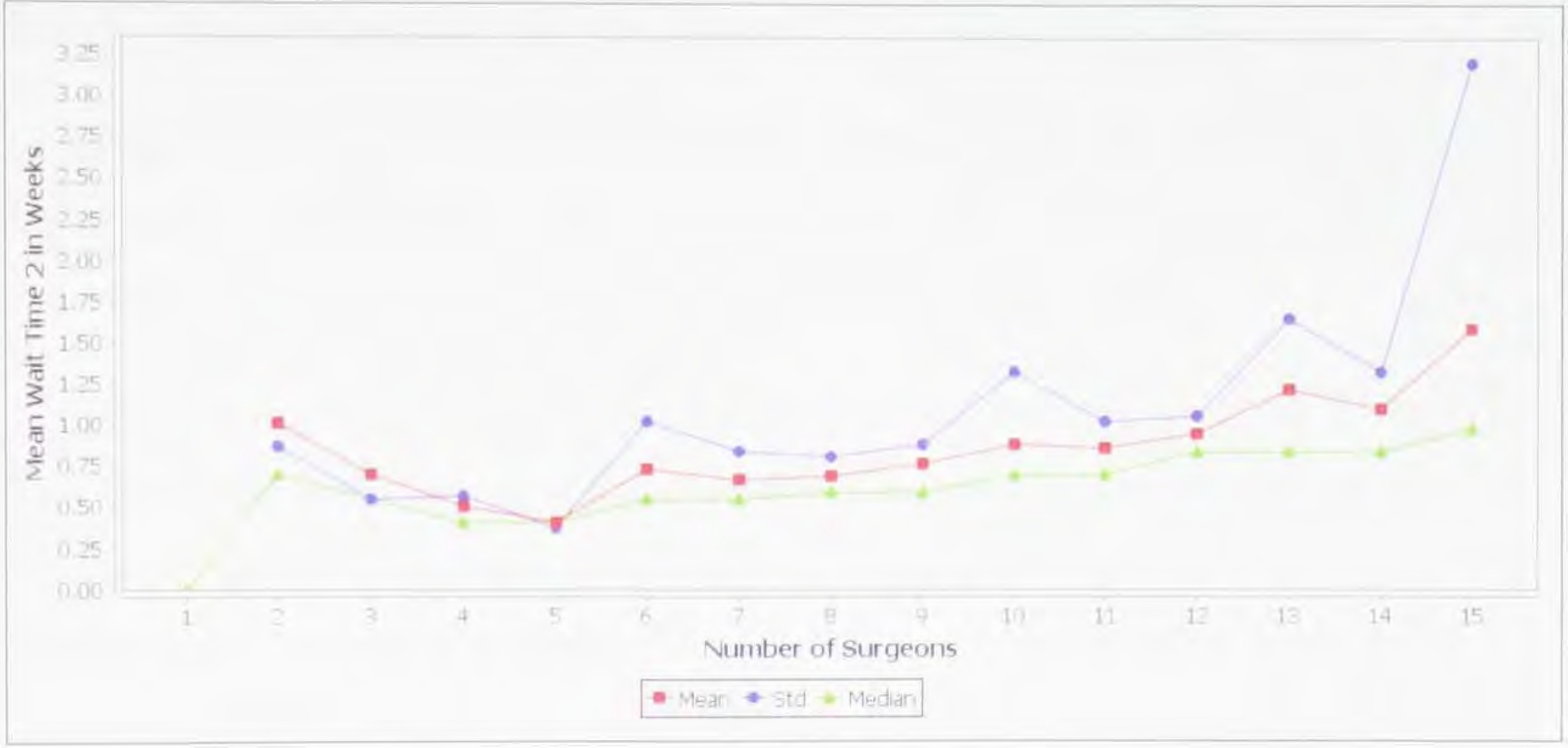

Figure 5.33: Experiment 10: Mean Wait Time 2 (by Varying the Number of Surgeons)

Observation on Percentage of Surgeries Done: We observe that the percentage of patients who underwent surgery is zero for one surgeon. This is because, in this case, all patients were referred to one surgeon only, and there were 500 backlog patients (250 patients for each backlog) in total. So after performing surgeries to all these backlog patients, the surgeon met new patients, and for some patients decision of surgery were made, but the surgeon was not able to start doing a surgery before the simulation time ends. The surgery percentage shows a huge improvement when there are two surgeons, that is 94%. This is the highest percentage, because there are two ORs, and two surgeons made optimum use of the ORs. For three to fifteen surgeons the percentage lies between 91% and 93%. In this case, despite of increasing the number of surgeons, the percentage is lower, because the number of ORs were not increased and each day maximum two surgeons performed surgeries in a round robin fashion. The percentage, for three to fifteen surgeons, remains almost same as patients were gradually assigned to more surgeons, as a result, surgeons were able to perform most of the surgeries as they had less number of patients. We know that in this model a surgeon performs surgery maximum two days a week.

5.2.3 Experiment 11: Impacts of Number of ORs

In this experiment we have changed the number of ORs from one to five and kept the number of surgeons fixed (five surgeons) to see what is the impact of this on wait time 2 if a fixed number of surgeons use different number of ORs.

Observation on Mean Wait Time 2: Mean wait time 2 is shown in fig. 5.34. The mean wait time 2 shows a difference between the number of OR is one and the number of ORs is two to five. This is why because, when there is only one OR, each surgeon is able to perform surgery only one day. But if the OR number is two or more, at least two surgeons perform surgery in parallel on each day, all five surgeons performed surgeries two days a week, and that reduces wait time.

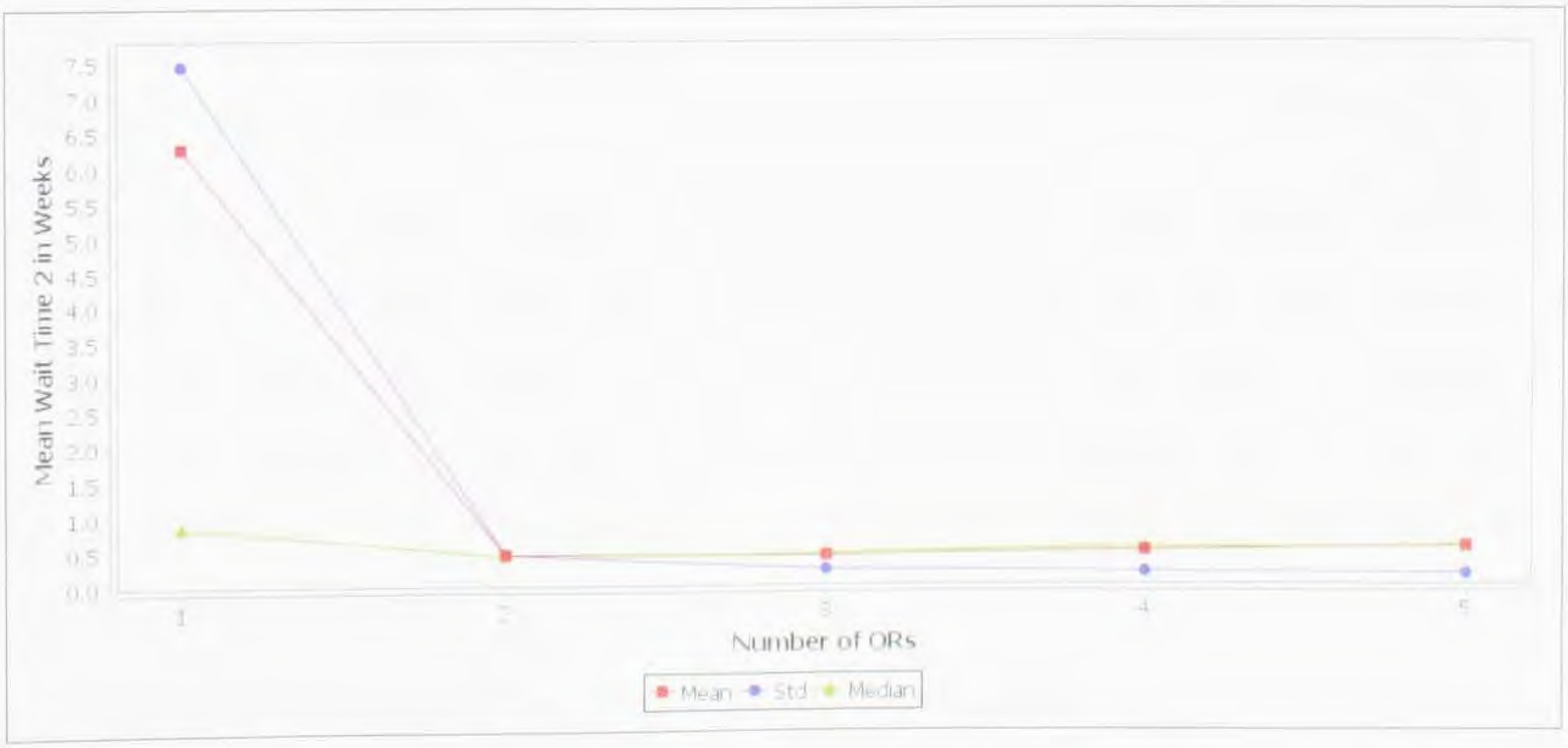

Figure 5.34: Experiment 11: Mean Wait Time 2 (by Varying the Number of ORs)

From the experiment results shown above, we see that in cataract surgery generic model (CSG model), the system performance depends on the number of ORs. The number of ORs should be at least half of the number of surgeons, this would make more surgeries with less wait times. For example, there should be at least four ORs if the number of surgeons is eight; then all surgeons will be able to perform surgery for maximum number of week days in a week set for the procedure.

5.3 Improved Performance of the Cataract Surgery Generic Model

In this section, we would like to recall some simulated results (percentage of surgeries done and wait time 2) of the two surgical models (NHCS model and CSG model) to see how much the CSG model gets improved performance than the NHCS model as there is no constraints in the CSG model. Here we present two scenarios.

The first scenario presents the percentage of surgeries done by each model with one and two ORs. It shows that if there were two ORs allocated for surgery, the CSG model would perform more surgeries (94%) with less number of surgeons, two surgeons only, whereas the NHCS model needs more than double surgeons, five surgeons, to perform 88% of surgeries.

The second scenario is about mean wait time 2. If we compare the fig. 5.17 and fig. 5.34, it is seen that, mean wait time 2 is near 6.5 weeks for CSG model whereas it is almost three times more, 20 weeks, for NHCS model when number of surgeons is five and number of OR is one. With same number of surgeons and two ORs, the mean wait times 2 for NHCS model and CSG model are almost 10 weeks and less than a week respectively.

The above discussion shows that the CSG model results in much more improved performance than the NHCS model.

5.4 Summary

In this chapter we have presented the simulation experiments for the two cataract surgical models and included observations. We have compared the experiment results with historical record of UHNBC to measure the accuracy of the proposed simulator; the simulated results are visually close to the original data.

Based on the observations, after doing the simulation study, we try to answer the research question: what are the main factors that cause the long wait times of patients. They are: (i) huge backlog patients; (ii) inefficient patient referral method; (iii) small number of OR allocation; (iv) only one assigned surgery day in each week for a surgeon; and (v) unused slates of surgeons. Use of priority scheduling system (MCWLP) to select the next patient for surgery did not show any improvement in wait times.

The answer to the last research question is here: in present situation, NH needs one more OR to meet the target wait time, if they want to continue the current surgical procedure.

The proposed two patient referral methods, refer patients to the surgeon with the least number of patients and uniform distribution of patients, showed significant improvement in the percentage of surgeries done and in wait time as well. Wait time 1 got slight improvement after adding different scenarios because surgeons meet patients all other days except the scheduled surgery day.

The simulated results of the generic model show the rate of improvement in the surgical procedure that does not have any constraints.

Finally we would like to say that, wait times are expected to go down if the present surgical procedure follows the findings of our observations, and especially the outcome of the generic model experiments.

Chapter 6

Conclusion

Long wait times for patients for elective surgery is generally a sign of inequality between supply and demand [36]. At present, this is a very commonly talked issue for health care systems and decision makers in the world. Reduction in long wait times in eye cataract surgery has got importance as one of the five major priority areas in the health care systems in Canada. Long wait times for patients in eye cataract surgery is gaining increased attention as a popular research topic, especially for developing simulation tools due to their flexibility in presenting complex and different scenarios.

In this thesis, we designed and developed a discrete event simulation tool in JAVA to study the cataract surgical procedure along with the scheduling of patients and OR(s). We focused on what are the causes of long wait times for patients, and how to reduce the wait times. We included two surgical procedure models in the simulation tool: Northern Health Cataract Surgical Model (NHCS Model), and a generic model that overcomes the OR scheduling constraints of Northern Health. The simulation tool has the following features: (i) both wait time 1 and wait time 2 of patients are included in the simulator; (ii) two proposed patient referral methods (refer patients to the surgeon with the least number of patients and uniform distribution of patients) are simulated and compared to the existing method (different percentage of patients for different surgeons) to see which method results in reduced wait times; (iii) it is used to analyse the impacts of changing the resources (OR and surgeon); and (iv) a priority scoring system, the Manitoba Cataract Waiting List Program (MCWLP) priority system, is simulated to select the right patient for next surgery and compared to the traditional FCFS policy to see which scheduling policy reduces wait time 2.

The main reasons of long wait times for patients found from the simulation study are:

- huge number of backlog patients
- the existing patient referral method
- only one OR allocated for cataract surgery
- only one surgery day assigned for each surgeon

The proposed two patient referral methods resulted in significantly less wait times for patients. The first method, refer patients to the surgeon with the least number of patients, showed the lowest wait times, the second method, uniform distribution of patients, took the next place, and the existing method had the longest wait times. The first two methods make an almost equal balance in the number of referred patients of surgeons. In this way some of the surgeons will not be overloaded with patients and their wait times will not be longer than others. The use of priority scheduling (MCWLP), to select the next patient for surgery, did not show any improvement in the wait time 2. This is because, the patients with major problems received surgery sooner based on priority, but the patients with minor problems had to wait longer. We observed that the generic surgical procedure resulted in much better performance than the NH surgical procedure. Our analysis showed that NH would meet the target wait time 2 (16 weeks) if one more OR (total of two ORs) is allocated for cataract surgery. If a surgeon uses two ORs alternatively for doing surgery on the scheduled day, the preparation time between two surgeries will be reduced, and as a result at least one more surgery will be done every day. This will reduce wait times for patients as well.

We expect that this simulation tool can be used by any health care authority to study the wait times in cataract surgical procedure. To the best of our knowledge, this is the first comprehensive study on the wait time 1 and wait time 2 together for cataract surgery along with the scheduling of patients and ORs. We also believe that this is the first study on the use of priority scheduling to schedule patients for cataract surgery in Northern British Columbia.

Increasing budget or number of resources is not always easy for any health care authority. So, this thesis strongly suggests that, if Northern Health authority changes the patient referral method, it would definitely reduce wait times for patients.

6.1 Limitations

This section addresses the limitations of this thesis. They are:

- backlog patients are distributed uniformly in the simulator to all surgeons as we did not have information about this. This distribution might affect the accuracy of the experimental results. This uniform distribution of patients understates the experimental result.
- backlog patients are not included in the calculation of performance metrics as their duration of wait times is unknown. The exclusion of backlog patients' wait times might show understated mean wait times. Mean wait times would be too long if backlog patients are included.

6.2 Future Directions

The proposed thesis could be expanded in many other directions, widely and accurately. Some of them are as follows:

- different percentage of distribution for backlog patients to surgeons could be simulated

- backlog patients could be included in the calculation of performance metrics
- more performance metrics could be included.
- animation could be added for visualization.
- more resources could be covered.
- other priority scoring systems could be tested.

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